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Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION

CR-115568
SVHSER-6040

This Report Contains Computer Prog Documentation

FINAL REPORT

DESICCANT HUMIDITY CONTROL SYSTEM

JUNE 1972

Proprietary

Prepared Under Contract No. NAS 9-11971

by

HAMILTON STANDARD
DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

by

Dr. Peter J. Lunde

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ABSTRACT

A new water vapor and arbon dioxide sorbent material (designated 'HS-C") has been developed for potential application to the Space Shuttle and tested at full scale. Capacities of two percent for carbon dioxide and four percent for water vapor were achieved using Space Shuttle cabin adsorption conditions and a space vacuum for desorption. Performance testing showed that water vapor can be controlled by varying the air process flow, while maintaining the ability to remove carbon dioxide.

A 2000 hour life test was successfully completed, as were tests for sensitivity to cleaning solvent vapors, vibration resistance, and flammability.

A system design for the Space Shuttle showed a 200 pound weight advantage over competitive systems and an even larger advantage for longer missions.

FOREWORD

This report has been prepared by the Hamilton Standard Division of United Aircraft Corporation for the National Aeronautics and Space Administration's Manned Spacecraft Center in accordance with Contract NAS 9-11971. The report covers work accomplished between June 21, 1971 and the date of issue.

Appreciation is expressed to the Technical Monitors, Mr. Richard J. Gillen and Mr. Frank Collier of NASA, Manned Spacecraft Center, for their guidance and advice.

This program was conducted under the direction of Mr. Fred H. Greenwood, Program Manager, and Dr. Peter J. Lunde, Program Engineer, with the assistance of:

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TABLE OF CONTENTS

	Page No.
SUMMARY	3
INTRODUCTION	5
OBJECTIVES	7
Material Review and Evaluation Objectives	7
Computer Program Objective	7
Laboratory Concept Development Objective	7
Design Concept Development Objective	7
CONCLUSIONS	9
RECOMMENDATIONS	11
SUMMARY REPORT	13
Desiccant Material Selection	13
Material Review and Evaluation	13
Secondary Properties	16
Computer Program	16
Laboratory Concept Development	19
Small Scale Tests	19
Large Scale Tests (Series I)	19
Large Scale Tests (Series II)	27
Large Scale Tests (Series III)	27
Design Concept Development	35

TABLE OF CONTENTS (Continued)

	Page No.
MATERIAL SELECTION AND PROPERTIES	41
Small Scale Apparatus Description	41
Objectives and Capabilities	41
Apparatus Description	41
Main Flow	41
Sampling	43
Test Canisters	46
Canister Temperature Control	46
Timing Sequence	46
Calibration	46
System Pressure	47
Inlet Gas Flow Rate	47
Sample Weight	47
Adsorption Time	47
Inlet and Outlet CO_2 and Water Vapor Partial Pressure	47
Calculations	50
Material Description	54
Evaluation	57
Material Variations	57
Substrate	57
Coating Weight	58
Coating Composition	58
Selected HS-C Material	58

TABLE OF CONTENTS (Continued)

	Page No.
HS-C Life Test	60
Solvent Tests	60
Objectives	60
Experimental Method	60
Results	62
Conclusions	62
Structural Tests	62
Flammability Tests	64
Results	64
Discussion	64
Toxicant Test	67
Discussion	67
Bromine	67
Ammonia	68
Toluene	68
Conclusion	68
Recommendations	68
COMPUTER PROGRAM DESCRIPTION	69
Introduction	69
Description and Mathematical Model	69
Adsorption and Desorption	69
Vacuum Desorption Pressure Distribution	73
Mathematical Formulation	74
Heat Transfer	76

TABLE OF CONTENTS (Continued)

	Page No.
Method of Solution	77
Program Capabilities	78
Program Options	78
Program Restrictions	79
Input/Output Parameters	79
Program Flow Charts	79
Program Symbol Definitions	80
Program Source Listings	80
Sample Case	80
LABORATORY CONCEPT DEVELOPMENT	81
Small Scale Development Tests	81
Test Objectives	81
Test Accuracy	82
Differences Between Large and Small Scale Tests	82
Test Canisters	82
Parametric Data Description	82
CO_2 Feed Concentration	86
Dew Point	86
Adsorption/Desorption Temperature	86
Inlet Flow Rate	86
Cycle Time	87
Large Scale Equipment Description	87

TABLE OF CONTENTS (Continued)

	Page No.
Large Scale Test Canister	92
Test Parameters	92
Flow Pattern	92
Calibrations	97
Large Scale Tests	102
Objectives	102
Experimental Method	105
Data Summary	105
Calculations	105
Parametric Data Discussion	108
Desorption Time, Temperature and Vacuum	108
Design for Desorption	109
Inlet CO_2 Concentration	109
HS-C SYSTEM DESIGN CONCEPT DEVELOPMENT	115
Concept Design	115
APPENDIX A Plan of Test & Test Data - HS-C Structural Tests	A-i
APPENDIX B Reproducibility	B-i
APPENDIX C Plan of Test - Toxicant Testing	C-i
APPENDIX D Input/Output Parameters - Flow Charts for Computer Program	D-i
APPENDIX E Test Plans - Large Scale Tests	E-i
APPENDIX F Data Summary Sheets - Large Scale Tests	F-i

LIST OF FIGURES

Figure No.	Title	Page No.
1	Effect of Coating Composition on HS-C Material	14
2	Effect of Coating Weight on HS-C Performance	15
3	IR&D Small Scale Tests - Life Test HS-C	17
4	HS-C Small Scale Parametric Tests - Effect of Partial Pressure CO_2 on Cyclic Capacity	20
5	HS-C Small Scale Parametric Tests - Effect of Humidity on Cyclic Capacity	21
6	HS-C Small Scale Parametric Tests - Effect of Adsorption/Desorption Temperature on Cyclic Capacity	22
7	HS-C Small Scale Parametric Tests - Effect of Gas Flow Rate on Cyclic Capacity	23
8	HS-C Small Scale Parametric Tests - Effect on Half Cycle Time on Cyclic Capacity	24
9	Test Canister Arrangement - Cover Removed	25
10	Test Canister Arrangement - Installed in Rig	26
11	HS-C Large Scale Parametric Tests - Effect of Air Inlet Temperature on Cyclic Capacity	28
12	HS-C Large Scale Tests - Effect of Bed Temperature on Cyclic Capacity	29
13	HS-C Large Scale Parametric Tests - Effect of Inlet Humidity on Cyclic Capacity	30
14	HS-C Large Scale Parametric Tests - Effect of Partial Pressure of CO_2 on Cyclic Capacity	31
15	HS-C Large Scale Parametric Tests - % CO_2 and H_2O Capacity vs Air Inlet Flow	32
16	Large Scale Parametric Tests - Effect of Desorption Time on Cyclic Capacity at P_{CO_2} = 5 mmHg	33
17	HS-C Large Scale Parametric Tests - Effect of Desorption Time on Cyclic Capacity	34

LIST OF FIGURES (Continued)

Figure No.	Title	Page No.
18	Sorbent Arrangement and Control	36
19	System Comparison HS-C and LiOH Condenser - (Mission Length - Days)	38
20	System Comparison HS-C and LiOH Condenser - (Crew Size)	39
21	Sorbent Evaluator	42
22	Small Scale Tests - Sample Chromatogram (One Analysis) Chart Speed 2 Divisions/Minute	44
23	Cyclic Test Data - Small Scale Apparatus	45
24	Gas Flow Calibration - Small Scale Tests	48
25	Small Scale Tests - CO_2 Calibration Gas Chromatograph	49
26	Small Scale Tests - H_2O Calibration Gas Chromatograph	51
27	Sorbent Evaluator Calculation Sheet	55
28	Small Scale Tests - Breakthrough Curve Tracings from Chromatogram	56
29	Canister Heating/Cooling System	88
30	Large Scale Tests - Rig 88 Block Diagram	89
31	Large Scale Test Apparatus	90
32	Large Scale Test Apparatus	91
33	Test Canister Design Layout	93
34	Test Configuration Header Layout	94
35	Large Scale Tests - Flow Pattern Within Heat Exchanger	95
36	Large Scale Tests - Canister Pressure Drop Calibration - Trace No. 1 - Brown	98

LIST OF FIGURES (Continued)

Figure No.	Title	Page No.
37	Large Scale Tests - P_{CO_2} Calibration	99
38	Large Scale Tests - Dew Point Calibration Trace No. 13 - Brown	100
39	Large Scale Tests - High Vacuum Pressure Gauge Calibration - Trace No. 14 - Red	101
40	Large Scale Tests - Rig Pressure Calibration Trace No. 23 - Blue	103
41	Large Scale Tests - Air Flow Calibration	104
42	Large Scale Parametric Tests - Humidity Calculations - Data Cycle 70 (Recorder Reading)	106
43	Large Scale Parametric Tests - Humidity Calculations - Data Cycle 70 (Converted Reading)	107
44	Large Scale Parametric Tests - Desorption Pressure vs Time	111
45	HS-C Large Scale Parametric Tests - ΔP vs Flow	112
46	HS-C Large Scale Parametric Tests - Cyclic Water Capacity	119
47	Coolant Loop Schematic	120
48	Schematic of Competitive System LiOH Condenser Used for Trade Study	121

LIST OF TABLES

Table No.	Title	Page No.
I	HS-C Sorbent Material Structural Testing Results	18
II	HS-C Life Tests	61
III	Solvent Tests	63
IV	Sorbent Evaluator Calculation Sheet	83
V	Test Parameters	96
VI	Design Requirements	116
VII	Optimization Procedure	118

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DESICCANT HUMIDITY CONTROL SYSTEM

SUMMARY

A new regenerable water vapor and carbon dioxide sorbent material has been developed and designated HS-C. Its ability to adsorb and subsequently vacuum desorb both gases simultaneously in a single homogeneous bed has been successfully demonstrated in a full scale test simulating Space Shuttle conditions.

Capacities of 2% for carbon dioxide and 4% for water vapor were achieved when 15 pounds of HS-C was prepared and parametrically tested in 5 and 10 pound lots under cabin adsorption and space vacuum conditions appropriate for the Space Shuttle mission. Performance testing showed that water vapor can be controlled by varying the HS-C process flow, while maintaining the ability for removal of carbon dioxide. Two hundred and nineteen hours of large scale performance testing were accumulated without degradation.

Small scale testing of HS-C was conducted for 2000 hours of cyclic performance without degradation. The material was shown to be insensitive to common cleaning vapors, and acceptable in flammability and vibration resistance. HS-C effluent gases were analyzed after heating to 180°F and 150-300 μgms NH_3 were evolved per gm of HS-C.

System design concepts applied using the Space Shuttle constraints showed that a system for simultaneous control of humidity and removal of CO_2 is feasible. Furthermore, the System using HS-C has a total equivalent weight advantage of 200 pounds over a competitive lithium hydroxide condensing heat exchanger system for atmospheric regeneration. For longer missions than the basic 7 day Space Shuttle mission, the advantage of an HS-C system increases since HS-C is not consumed in the regeneration process.

INTRODUCTION

Metabolic water vapor and carbon dioxide have historically been removed from the spacecraft cabin by a condensing heat exchanger and lithium hydroxide (LiOH), respectively. The condensing heat exchanger offers the possibility of water reclamation and the LiOH system adsorbs large quantities of CO_2 in a small bed. However, these advantages fade in the Space Shuttle because of the ready availability of fuel cell product water and the longer mission length and larger crew size, which require increasing quantities of the non-regenerable LiOH.

A new water vapor and carbon dioxide sorbent called HS-C has now been developed to remove the metabolic products from the cabin using a single sorbent bed. It can be regenerated by a dry gas purge or a hard vacuum (50 microns) at the adsorption temperature, or by a mild vacuum (1/2 psia) at higher temperatures (200°F).

HS-C is made from a spherical porous substrate (diameter about 0.5 mm), which is coated with a thick non-volatile liquid which chemically adsorbs CO_2 and H_2O.

HS-C is currently of interest to the designers of the Space Shuttle life support system for removal of metabolic water and carbon dioxide from the cabin. Competing systems are the flight-proven lithium hydroxide, which requires careful preflight preparation of the high capacity non-regenerable material plus the usual condensing heat exchanger for humidity control; and a silica gel molecular sieve system which shares some of HS-C's system advantages but can be poisoned with water vapor.

The HS-C system is especially desirable because it requires no liquid loop connections, needing only space vacuum and electrical connections to perform within the cabin environment. The material need not be replaced between flights since it can be regenerated easily on the ground with a dry purge.

OBJECTIVES

The basic objective of this program was to develop a regenerable desiccant system concept for controlling the humidity and CO_2 level in the cabin of a Space Shuttle vehicle. To support this objective it was necessary to develop HS-C from a laboratory scale research material to a first class contender for the Shuttle mission. The first large scale preparations were made, performance of a full sized bed was investigated, and other properties (fire, toxicity, structural capability, etc.) were evaluated. A computer description of the material was developed and trade-off studies were conducted, which showed the material's basic superiority over a LiOH system.

The program was divided into four tasks:

- Material selection, preparation and properties.
- Computer program.
- Laboratory concept development.
- Design concept development.

The objectives of each task are listed below.

MATERIAL REVIEW AND EVALUATION OBJECTIVES

- To review available HS-C desiccant/CO_2 control materials to assure selection of an HS-C formulation most suitable to the specified performance requirements.
- To prepare the quantities of HS-C required for small and large scale testing and for delivery to NASA.
- To conduct solvent tests to assure that HS-C shall not be affected by solvents normally used in Manned Spacecraft Programs.

COMPUTER PROGRAM OBJECTIVE

- To generate a base computer program modeling HS-C which will allow design parameter determination and concept selection.

LABORATORY CONCEPT DEVELOPMENT OBJECTIVE

- To perform laboratory level development tests to adequately verify the computer program accuracy and adequacy.

DESIGN CONCEPT DEVELOPMENT OBJECTIVE

- To develop a system design concept applicable to the Space Shuttle including schematics, component operating parameters, and redundancy features.

CONCLUSIONS

1. HS-C preparations on a five to ten pound scale have been successfully made. Quality control procedures have been devised such that preparations of up to 100 pounds over a few months are practical.

2. HS-C properties can be tailored, to a degree, by the use of different coating agents and coating quantities.

3. HS-C has been cyclically tested for 2000 hours in a Shuttle-type cycle without degradation.

4. Vibration of HS-C produced no change in performance, pressure drop, or physical conditions.

5. Using atmospheric air, the flammability of HS-C was acceptable according to Category B of D-NA-0002, Procedures and Requirements for Flammability and Offgassing Evaluation of Manned Spacecraft Nonmetallic Materials. The material also passes Category C when a container is used which is representative of that projected for a spacecraft. Proper design of the flight canister must be assured before the configuration will be acceptable to NASA.

6. Common cleaning solvent vapors caused negligible performance degradation of HS-C.

7. 150 to 300 μgm of ammonia per gram of HS-C were generated when heated to 180°F in accordance with Specification MSC-PA-D-67-13.

8. Other toxicants (toluene, brominated hydrocarbons) were found which originated in impurities in test apparatus or raw materials. These impurities can be removed by improved test and preparational procedures.

9. A computer program has been developed which can predict cyclic performance of HS-C beds in the Shuttle configuration.

10. Full scale tests of HS-C for Shuttle type operation show a capacity of 2% for carbon dioxide and 4% for water vapor with a 40 minute desorb and 40 minute adsorb at Shuttle nominal conditions.

11. HS-C capacity for water and carbon dioxide is independent of the inlet temperature and nearly independent of inlet carbon dioxide concentration above 3mmHG. HS-C capacity for carbon dioxide is independent of the bed temperature when the same temperature is used for adsorption and desorption. Nominal conditions were such that increased adsorption cycle time or inlet air flow had no effect on carbon dioxide capacity, although water capacity was increased. Important capacity increases for CO_2 were noted with increased desorption time, decreasing desorption pressure, decreased bed thickness, a smaller HS-C particle size. Important increases in water capacity were noted with increase of inlet air flow, humidity or bed temperature.

12. In a realistic Shuttle system, a full trade-off of the atmospheric regeneration system indicates that HS-C has a 200 pound weight advantage over a LiOH condensing heat exchanger system for designs with crew sizes of 2-14 men. Since the HS-C is completely regenerable, its weight advantage increases with mission time.

13. Water capacity sizes the HS-C system proposed for the Shuttle. Future HS-C material development should emphasize increased water capacity, not capacity for carbon dioxide.

RECOMMENDATIONS

1. The mechanism responsible for the off-gassing of ammonia from HS-C should be investigated and means for reducing or eliminating ammonia evolution should be pursued.

2. Full scale performance verification testing of HS-C material with reduced ammonia evolution should be verified.

3. Kinetic constants for the HS-C material to be used in the Space Shuttle simulation should be obtained for use with the computer program developed under this contract.

4. The utility of HS-C for a Space Shuttle mission should be demonstrated further by designing, fabricating and testing a two-canister breadboard system incorporating projected heat interchange equipment and finding the concentration of water and carbon dioxide achieved as these constituents are added to a cabin environment in simulation of various crew activities.

SUMMARY REPORT

This section summarizes the material presented in detail in later sections, but without experimental detail and supporting arguments.

DESICCANT MATERIAL SELECTION

The first objective of this contract was to produce a candidate sorbent material and evaluate its sorptive qualities and secondary properties.

Material Review and Evaluation

HS-C designates a class of regenerable sorbent materials made by coating a porous spherical substrate with an amine based liquid which adsorbs both water and CO_2.

A number of HS-C preparations were made to find the highest capacity material. Variations explored were:

Coating Agent:	(1)	Polyethylenimine (Molecular weight 1800)
	(2)	Tetraethyleneamine pentamine
Coating Amount:	(1)	Percent by weight
Substrate:	(1)	24-28 mesh material (acrylic ester)
	(2)	30-40 mesh material (acrylic ester)

Figure 1 shows the difference in performance for two coating agent compositions over a range of CO_2 inlet compositions. The Tetraethyleneamine (TEPA) coating produces 10% better CO_2 capacity and 50% better water capacity than the Polyethylenimine (PEI) coating. PEI was nonetheless chosen for coating agent because there was little experience with TEPA, leading to doubts regarding secondary properties, such as toxicity and volatility. Polymerization of a TEPA coating in place is technically feasible and would undoubtedly solve such latent problems, but such work was beyond the scope of this program.

Coating weight variations were explored for the PEI coating. Figure 2 shows a typical curve from a coating optimization, showing that too little coating leaves some of the material uncoated, and too much clogs rather than coats the deeper substrate pores with PEI.

Substrate variations were made by using different sized substrate particles. The smaller particles (30-40 mesh) showed somewhat higher CO_2 and H_2O capacity (Figure 2), an effect attributed to a better intra-particle diffusion rate.

EFFECT OF COATING COMPOSITION ON HS-C PERFORMANCE

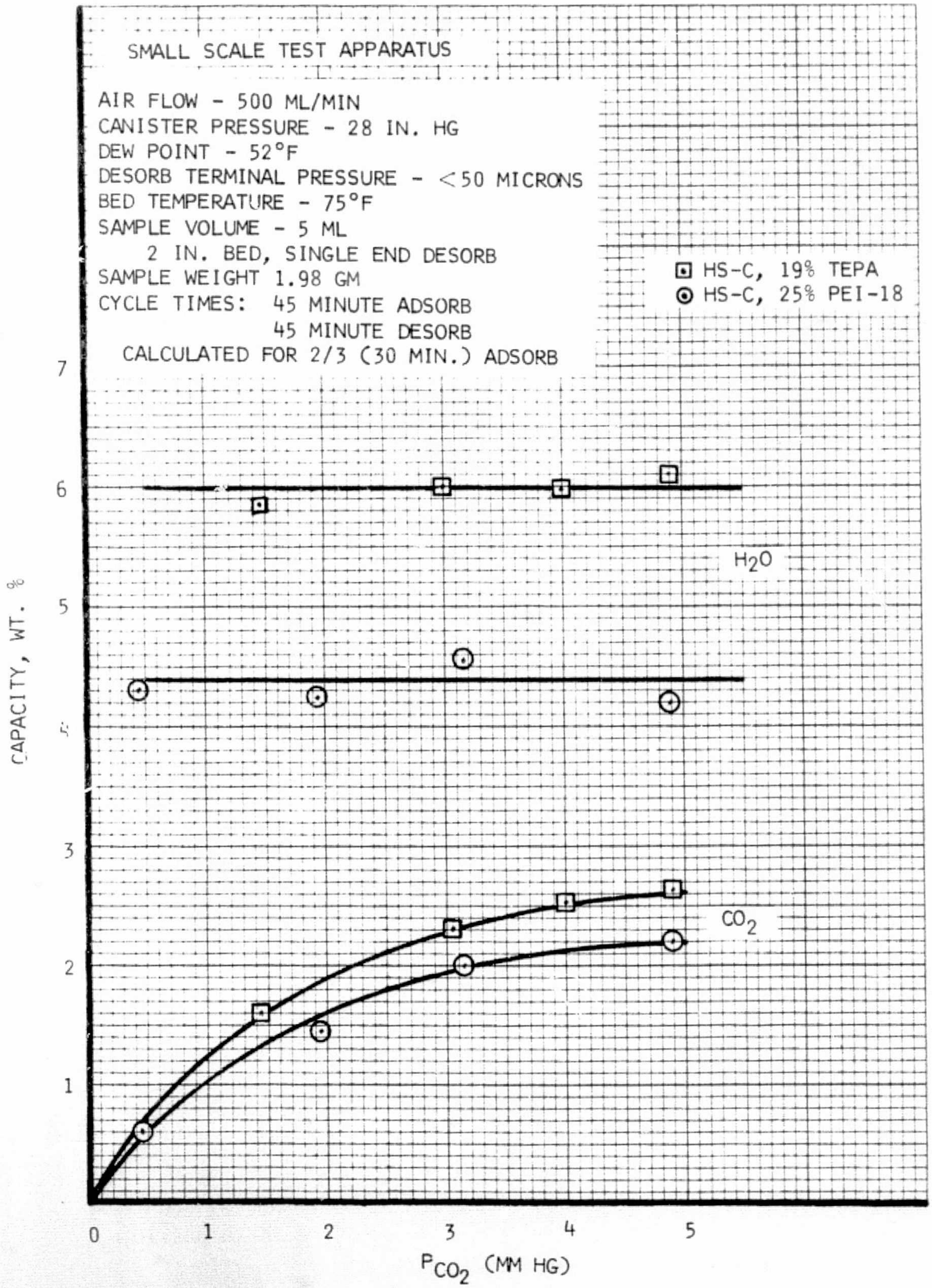


FIGURE 1

EFFECT OF COATING WEIGHT ON HS-C PERFORMANCE

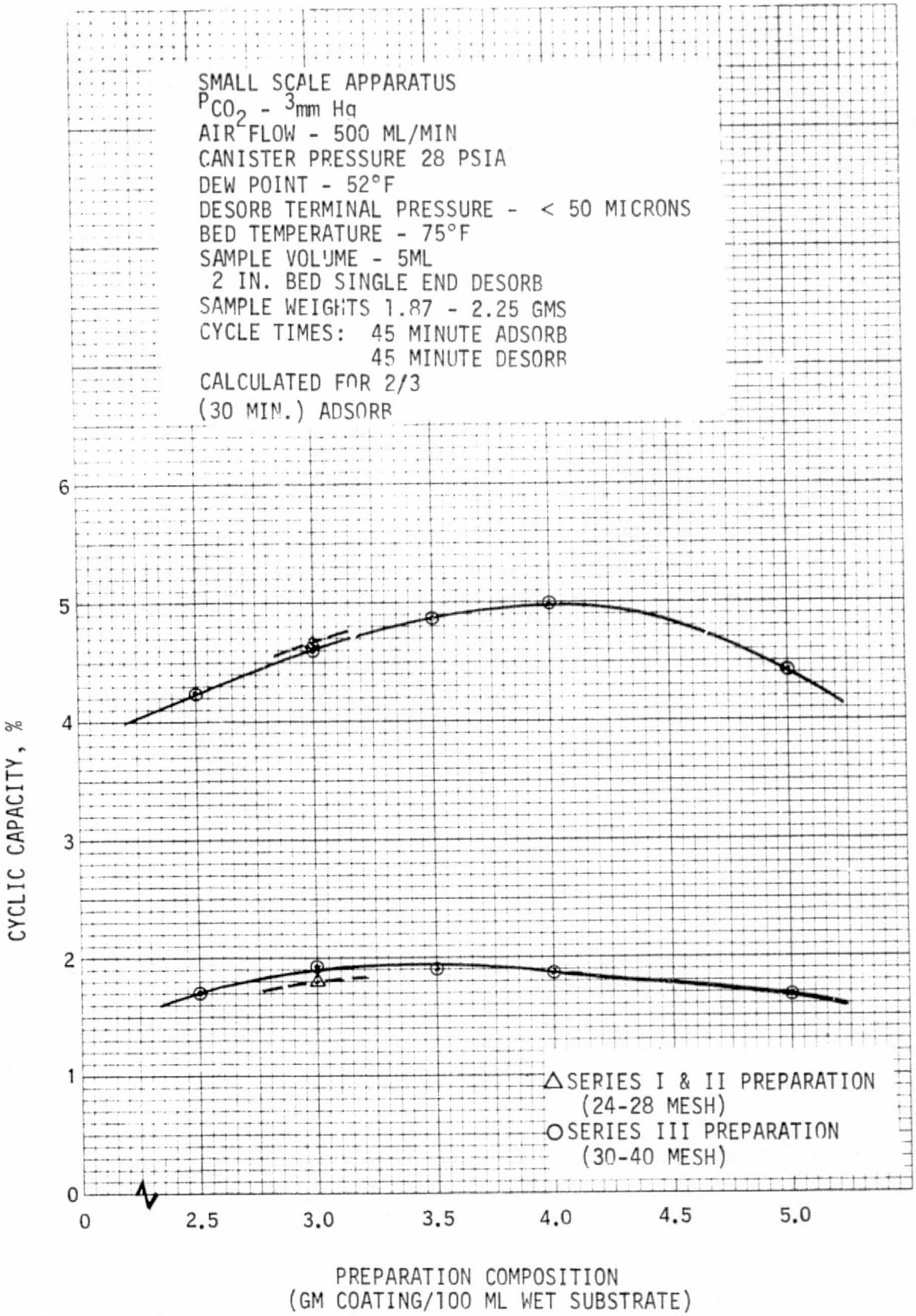


FIGURE 2

Bed depth also has an important effect on performance. The deeper the bed, the more difficult the desorption, due to the longer inter-particle diffusion path length.

The HS-C preparations used for development testing are summarized below:

	Bed Size	Particle Size	wt % PEI 18	Bed Depth
Small scale tests (IR&D Material)	2 gm	24-28 mesh	24.2	4 in*
Large scale tests (Series I)	10 lb	24-28 mesh	24.2	3 in
Large scale tests (Series II)	5 lb	24-28 mesh	24.2	1-1/2 in
Large scale tests (Series III)	5 lb	30-40 mesh	20.6	1-1/2 in

Secondary Properties

Under Hamilton Standard's general Independent Research & Development (IR&D) Atmosphere Revitalization development program a life test, a structural test, and a flammability test were run on the HS-C developed for Series I and II. As a part of this contract, tests were run to determine the poisoning effect of solvents on HS-C and to analyze the kinds of toxicants HS-C generates when heated 100°F above the normal operating temperature (180°F).

HS-C was cycled for 2000 hours without degradation of performance (Figure 3). Severe shaking of a loaded canister (simulating launch) produced no change in performance, physical condition, or pressure drop (Table I).

When common cleaning solvents were introduced into the sorbent feed gas, little effect was noted. A maximum of 10% degradation was noted at the extreme data scatter. Gases evolved on heating HS-C were found to be primarily in three categories. One of these was traced to test rig manometer fluid and one to an impurity in the substrate. The final impurity, ammonia, was an impurity in the HS-C coating. Except for the ammonia, it is believed that these gases can be eliminated by improved preparational procedures. Ammonia generation levels were 150-300 μ gms NH_3 per gram of HS-C when tested in accordance with Specification MSC-PA-D-67-13.

COMPUTER PROGRAM

A second objective of the contract was to develop a computer program describing HS-C performance for use in concept selection. A mathematical

*Actually 2 inches, single end desorb.

IR&D SMALL SCALE TESTS
LIFE TEST HS-C

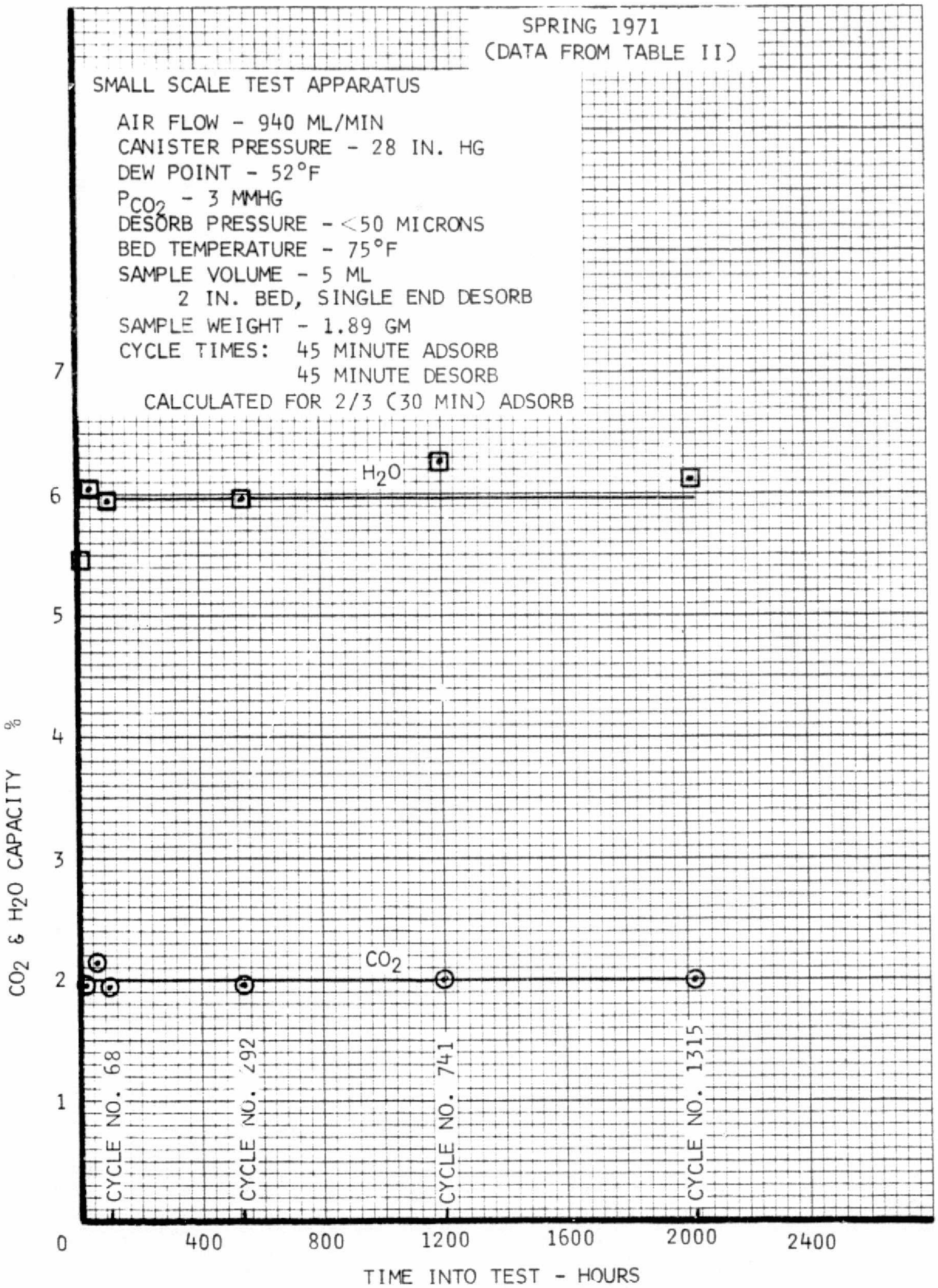


FIGURE 3

HS-C SORBENT MATERIAL STRUCTURAL TESTING RESULTS

Test	Parameter	Before Vibration	After Vibration
Dusting Resistance	% Non-spherical Beads	1.35%	1.05%
Apparent Density	Grams/Milliliter	0.402	0.402
CO_2 Adsorption	% by Weight	1.69	1.71
H_2O Adsorption	% by Weight	5.14	5.27
Pressure Drop	ΔP Across Vibration Test Canister	See Curve Below	

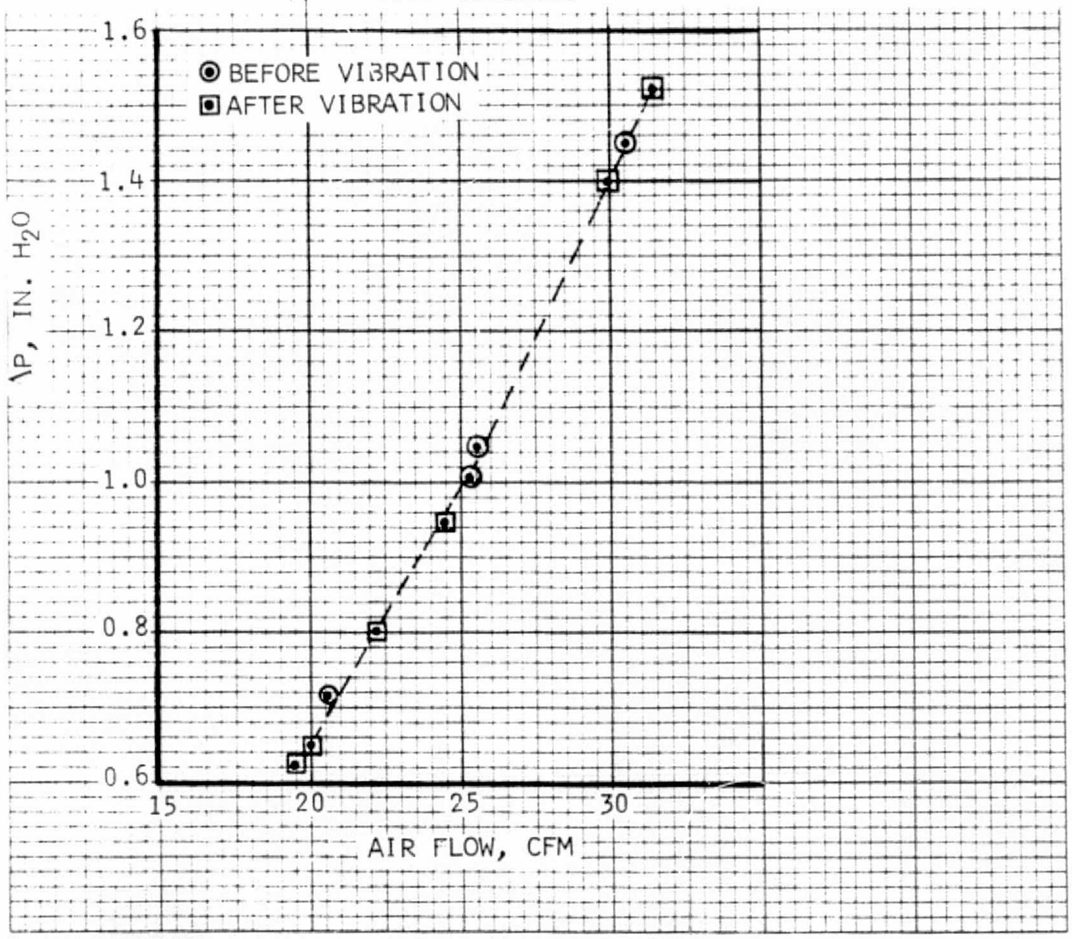


TABLE I

N1

model for HS-C adsorption and desorption performance was developed and combined with heat transfer relations and heat and material balances to construct a computer program which predicts water and CO_2 adsorption or desorption rates along the length of the bed, calculating effluent gas composition and residual bed loadings as a function of time.

Single adsorption or desorption cycles, or a succession of adsorption/desorption cycles can be calculated. The bed can be cooled or heated during adsorption and desorption by cross-flow heat exchange with constant temperature cooling or heating fluid, typically cabin air. Desorption can be handled by dry gas purge or by high vacuum. Output data is printed or if desired can be plotted using the standard computer output print and paper.

Kinetic constants were developed empirically by reference to those determined for an earlier material and the test results from this program.

LABORATORY CONCEPT DEVELOPMENT

A third objective of the contract was to verify computer program accuracy and adequacy through laboratory testing. The two HS-C materials selected in an earlier phase were tested in the laboratory in small scale (2 gm) and large scale (5 and 10 pounds) tests.

Small Scale Tests

The larger mesh size material was exhaustively tested on a small scale, with twelve tests exploring performance variations due to changes in CO_2 feed concentration, inlet dew point, adsorption/desorption temperature, inlet flow and cycle time.

CO_2 capacity fell appreciably when CO_2 concentration in the feed was below P_{CO_2} = 3 mmHg (Figure 4). Water capacity rose rapidly with increasing dew point, doubling between 40°F and 60°F (Figure 5). Desorption/adsorption temperature did not affect CO_2 capacity, but lower temperatures favored increased H_2O capacity (Figure 6). Increased inlet gas flow increased performance up to the nominal conditions but not beyond, showing that mass transfer to the material was adequate at nominal conditions (Figure 7). Similarly, increasing cycle length improved capacity up to the nominal conditions, but a further increase made only a small improvement (Figure 8).

Large Scale Tests (Series I)

The larger mesh size HS-C material was tested in a large scale configuration (10 lbs of HS-C). The test canister was a modified fin-tube heat exchanger 14 x 14 x 3 inches with an air flow path three inches long (Figures 9 and 10), desorbed at both ends to a high capacity vacuum system. Fifteen parametric tests were run totaling 219 continuous hours of testing.

HS-C SMALL SCALE PARAMETRIC TESTS

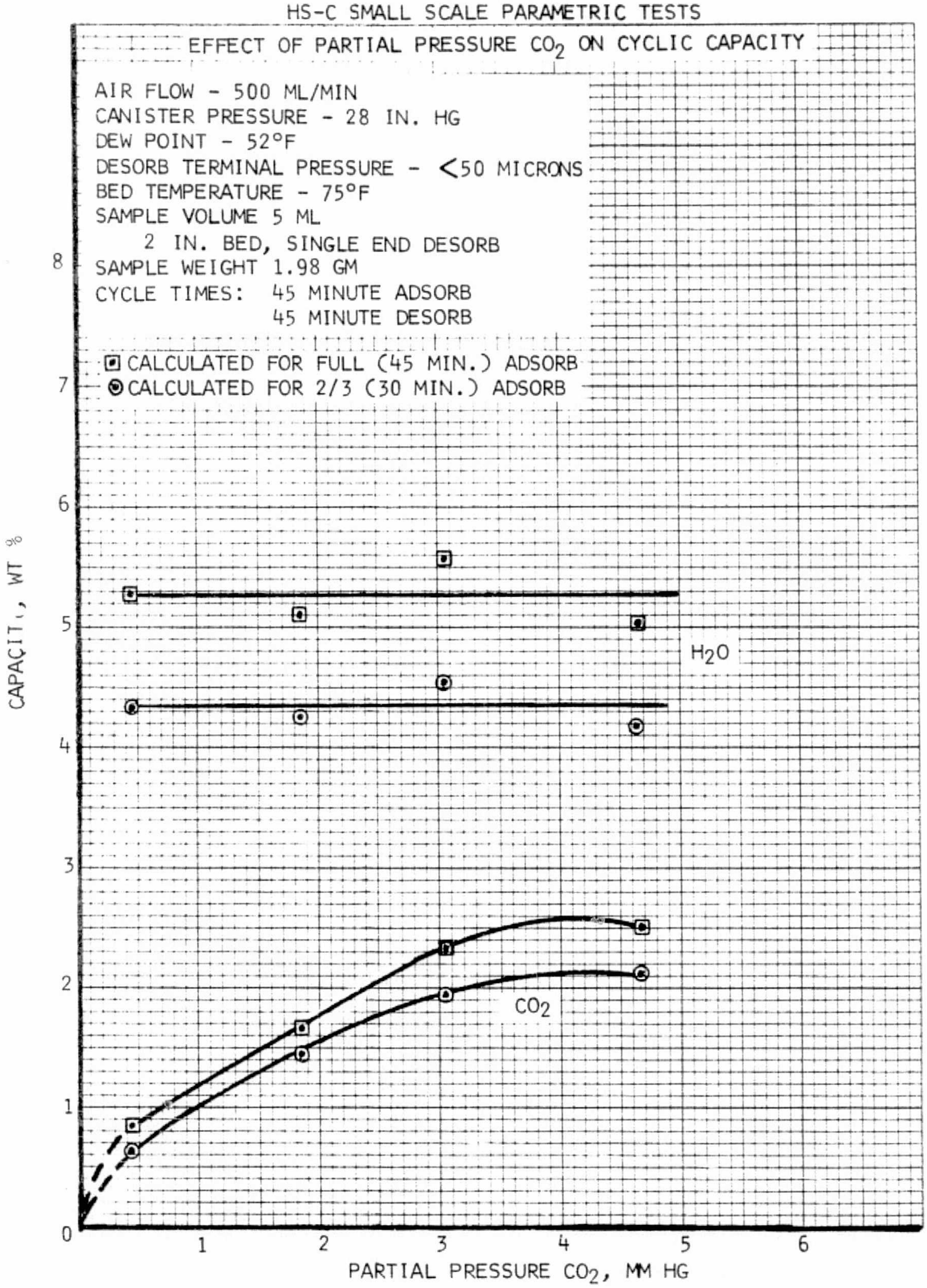


FIGURE 4

HS-C SMALL SCALE PARAMETRIC TESTS

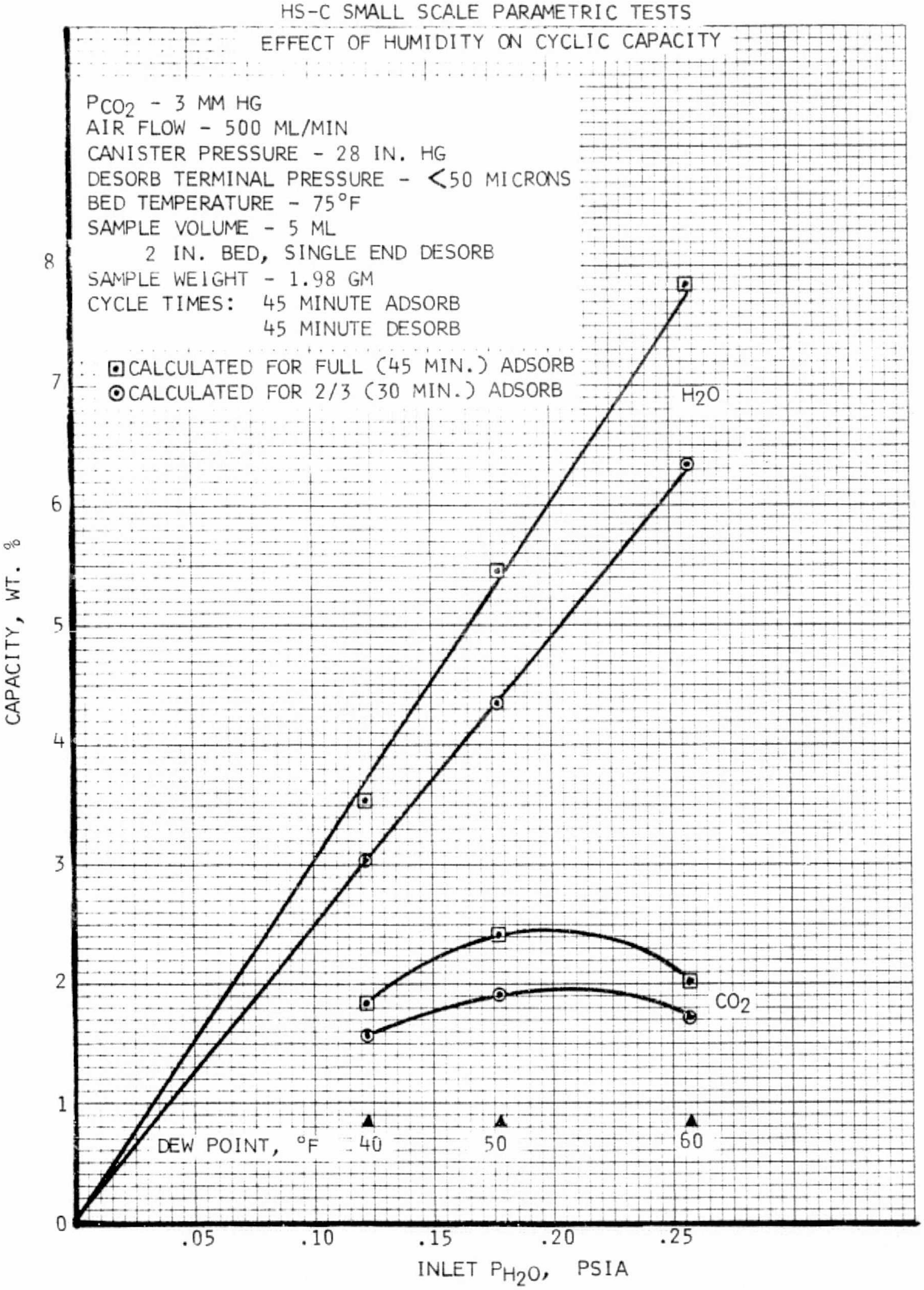


FIGURE 5

HS-C SMALL SCALE PARAMETRIC TESTS

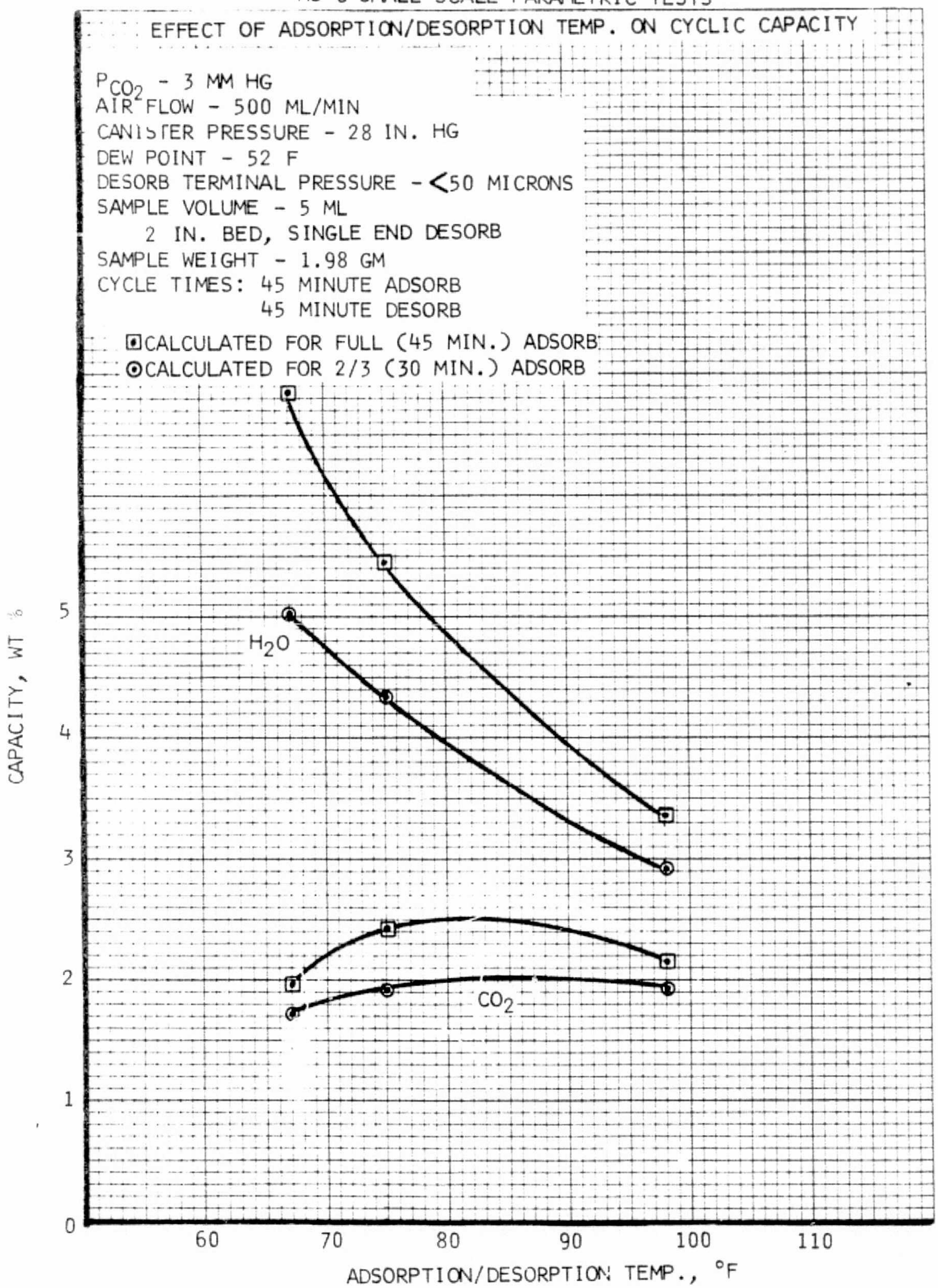


FIGURE 6

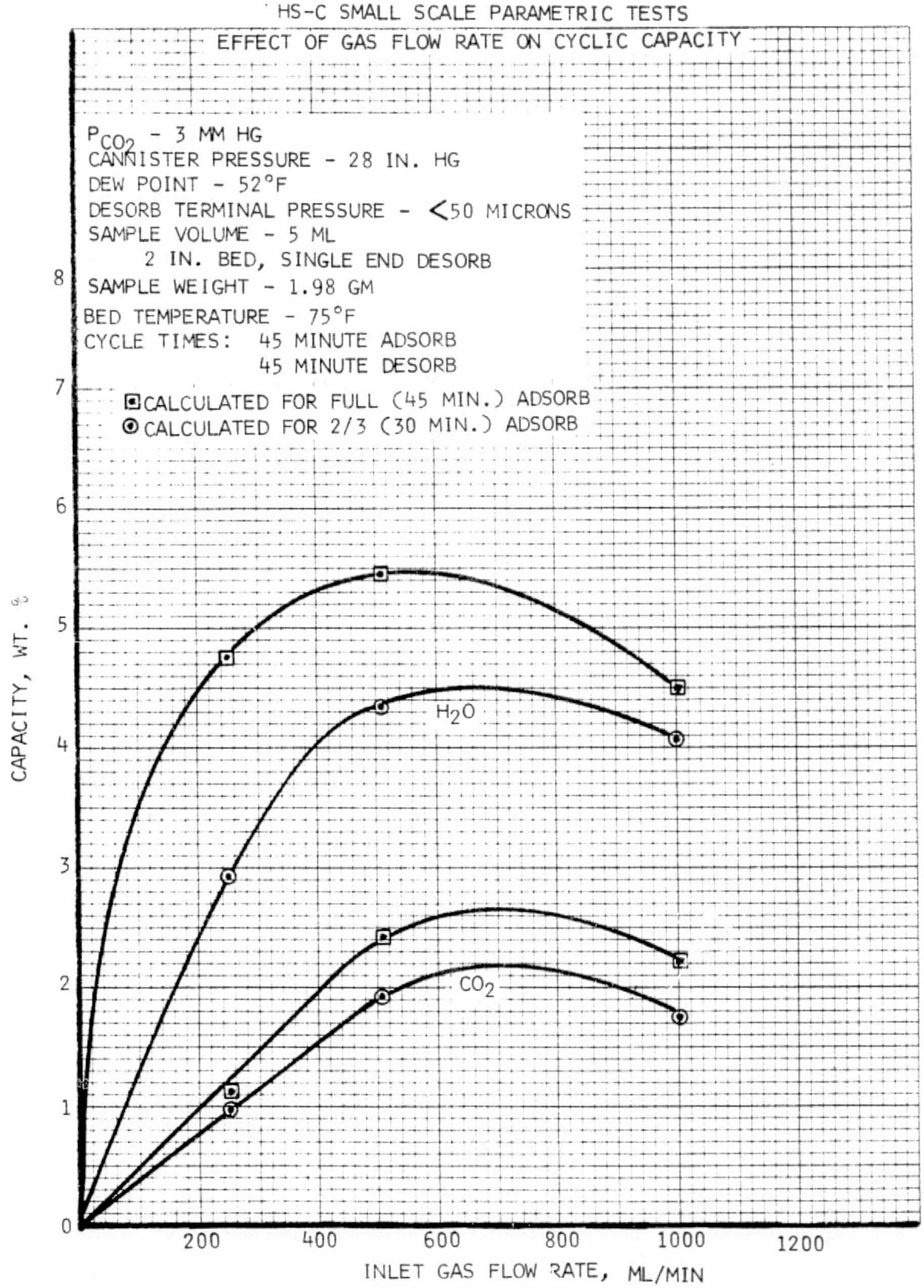

HS-C SMALL SCALE PARAMETRIC TESTS
EFFECT OF GAS FLOW RATE ON CYCLIC CAPACITY
P_{CO_2} - 3 MM HG
CANNISTER PRESSURE - 28 IN. HG
DEW POINT - 52°F
DESORB TERMINAL PRESSURE - <50 MICRONS
SAMPLE VOLUME - 5 ML
2 IN. BED, SINGLE END DESORB
SAMPLE WEIGHT - 1.98 GM
BED TEMPERATURE - 75°F
CYCLE TIMES: 45 MINUTE ADSORB
45 MINUTE DESORB
CALCULATED FOR FULL (45 MIN.) ADSORB
CALCULATED FOR 2/3 (30 MIN.) ADSORB
H_2O
CO_2
CAPACITY, WT. %
0
1
2
3
4
5
6
7
8
200
400
600
800
1000
1200
INLET GAS FLOW RATE, ML/MIN

FIGURE 7

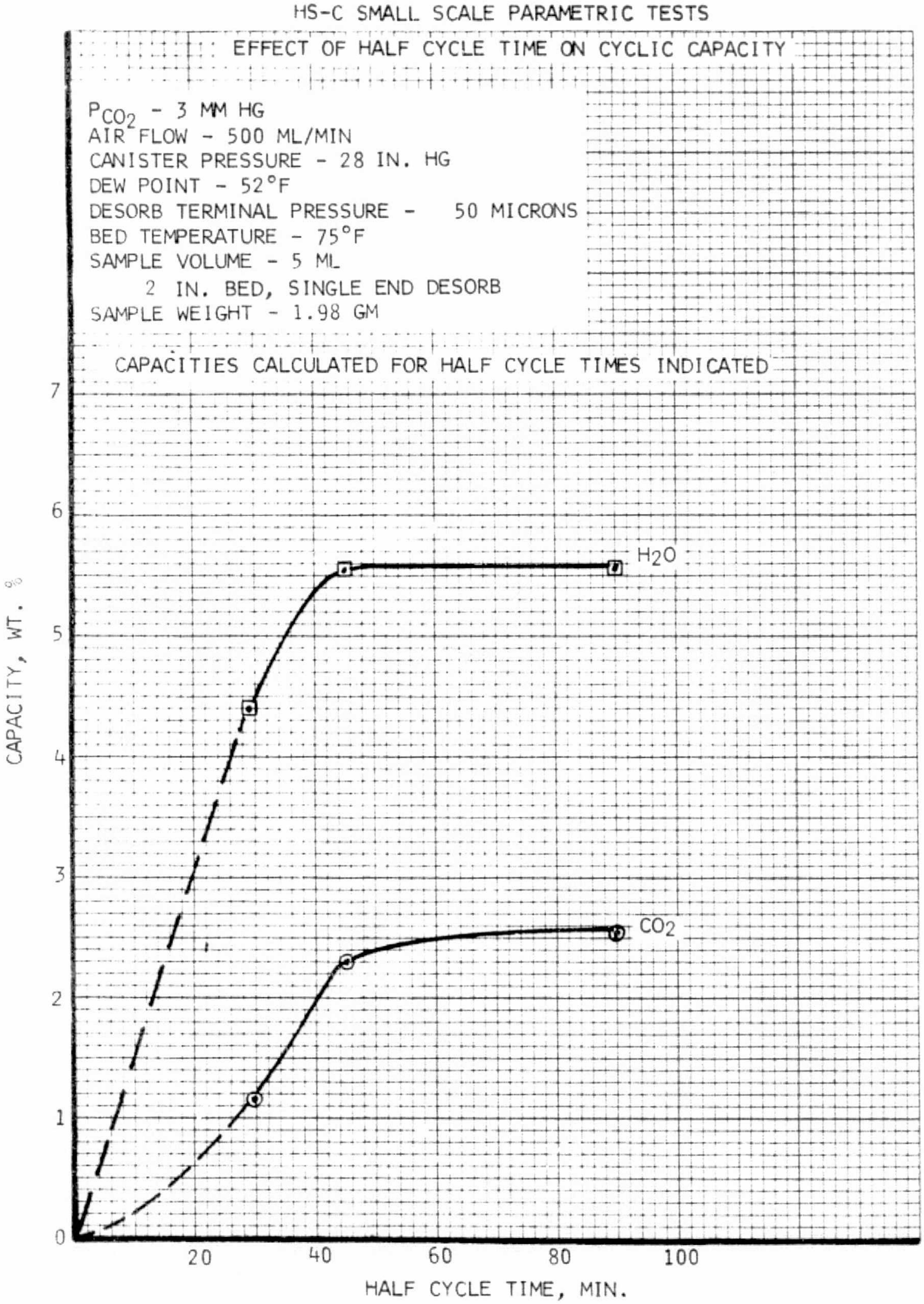

HS-C SMALL SCALE PARAMETRIC TESTS
EFFECT OF HALF CYCLE TIME ON CYCLIC CAPACITY
P_{CO_2} - 3 MM HG
AIR FLOW - 500 ML/MIN
CANISTER PRESSURE - 28 IN. HG
DEW POINT - 52°F
DESORB TERMINAL PRESSURE - 50 MICRONS
BED TEMPERATURE - 75°F
SAMPLE VOLUME - 5 ML
2 IN. BED, SINGLE END DESORB
SAMPLE WEIGHT - 1.98 GM
CAPACITIES CALCULATED FOR HALF CYCLE TIMES INDICATED
H_2O
CO_2
CAPACITY, WT. %
0
1
2
3
4
5
6
7
20
40
60
80
100
HALF CYCLE TIME, MIN.

FIGURE 8

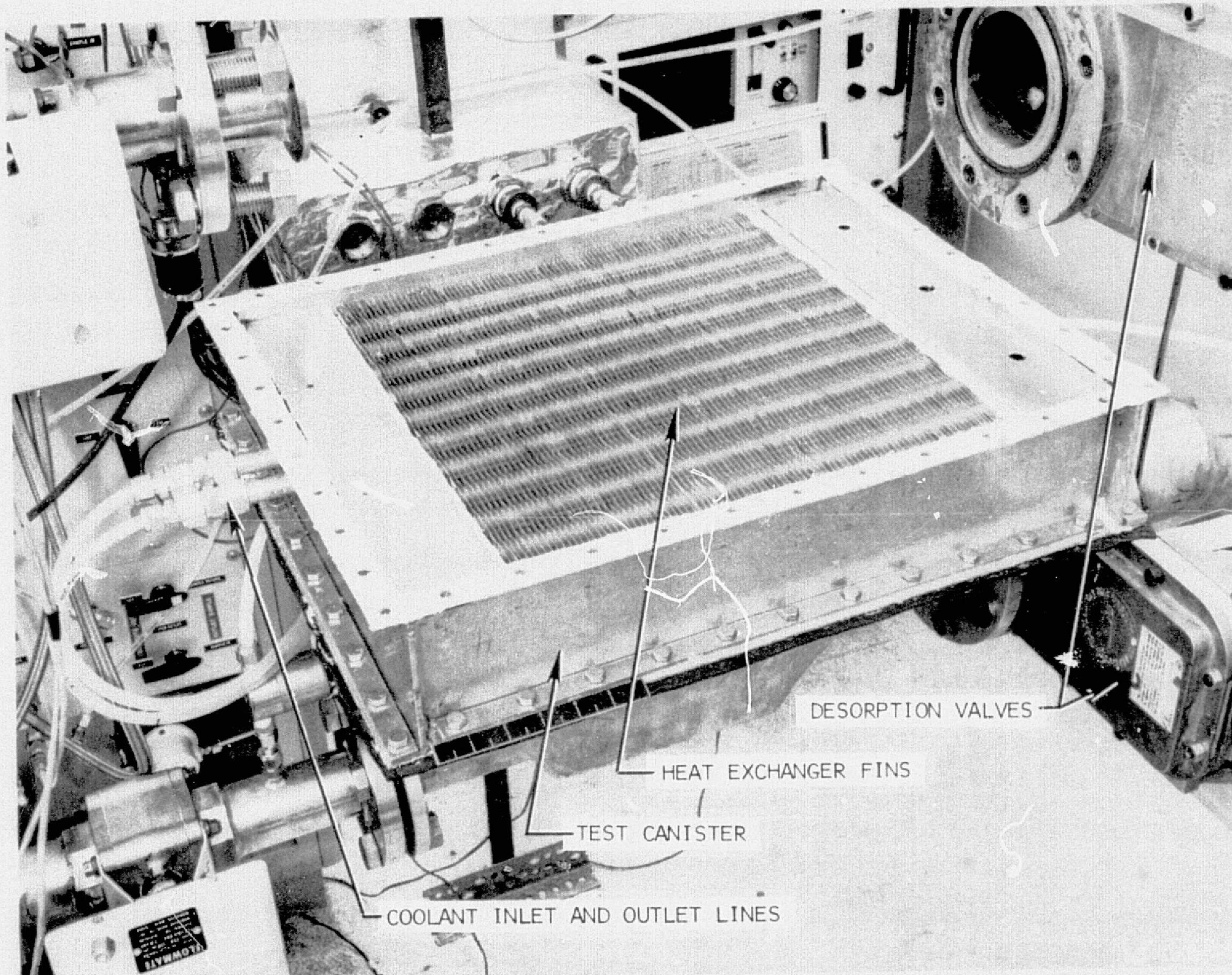
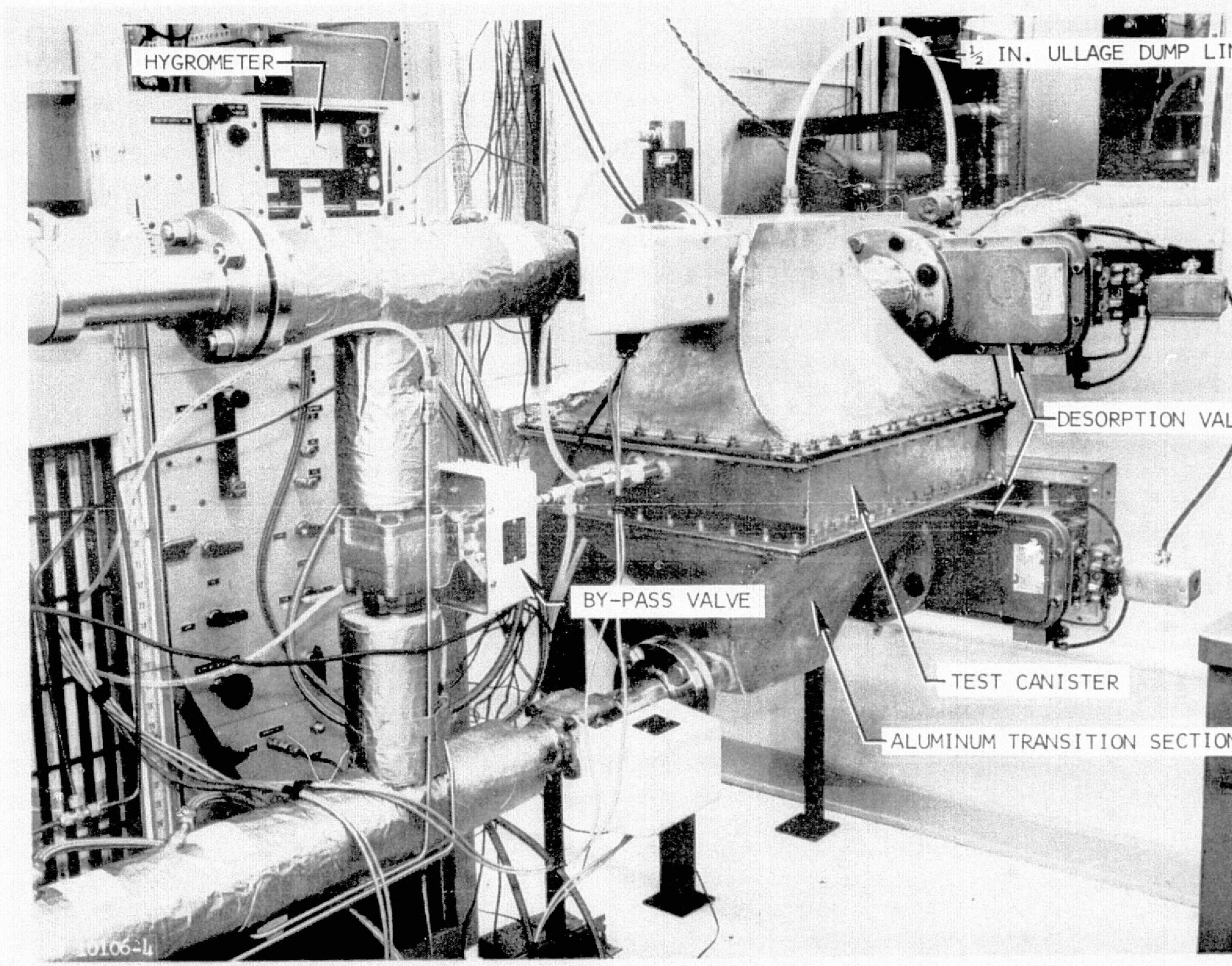


FIGURE 9

TEST CANISTER ARRANGEMENT
(COVER REMOVED)

FIGURE 10



TEST CANISTER ARRANGEMENT
(INSTALLED IN RIG)

Performance changes resulting from changes in inlet air temperature, inlet dew point, bed adsorb/desorb temperature, inlet CO_2 concentration, inlet air flow, cycle time, and desorption pressure were explored.

Changes in inlet air temperature and bed adsorb/desorb temperature had little effect on performance (Figures 11 and 12). Changes in inlet CO_2 concentration did not affect H_2O adsorption and vice versa (Figures 13 ,14).

Other effects were qualitatively those expected from the small scale tests. Inlet dew point had a large effect on water capacity, almost doubling over a 10°F dew point change (Figure 13). Inlet CO_2 concentration affected capacity appreciably up to 3 mmHg, but only slightly above that pressure (Figure 14). Inlet air flow did not affect CO_2 capacity, but markedly affected the H_2O capacity which was much further from saturation at the test conditions (Figure 15).

Cycle time affected performance considerably because of the importance of desorption time (Figure 16). A very long desorption time (overnight) gave 2.6% CO_2 capacity by weight. Two percent cyclic capacity was reached with a 80 minute desorption, while with 30 minutes desorption time, the capacity was about 1.6%. Water capacity was relatively unaffected, suggesting that water is desorbed more readily than CO_2.

Desorption pressure was quite important, with HS-C requiring low vacuum for best performance (Figure 17).

Large Scale Tests (Series II)

Series II tests were run with 5 pounds of HS-C in the same test canister used for Series I. Bed thickness was reduced to 1-1/2 inches, enhancing CO_2 capacity by reducing the inter-particle pressure drop during desorption. The same HS-C material was used as for Series I. Twenty-two additional test hours were accumulated and variations in cycle time were explored (Figure 16). About 10% additional capacity was achieved by decreasing the bed thickness in this manner, giving cyclic capacities of 1.9% for CO_2 and 3.2% for water vapor at 45 minutes desorption time.

Large Scale Tests (Series III)

Five pounds of smaller mesh HS-C material was tested in the large scale canister. As in Run Series II, bed depth was 1.5 inches. 228 hours of continuous operation were accumulated at nine parametric test conditions. Figure 16 shows the enhancement of capacity which the smaller particles gave. A capacity of 2% for CO_2 and 5% for water vapor was achieved with a 40 minute desorption. When water vapor and carbon dioxide partial pressures and bed temperature were raised to high nominal conditions, 2.1% capacity for CO_2 and 4% for H_2O were achieved.

HS-C LARGE SCALE PARAMETRIC TESTS

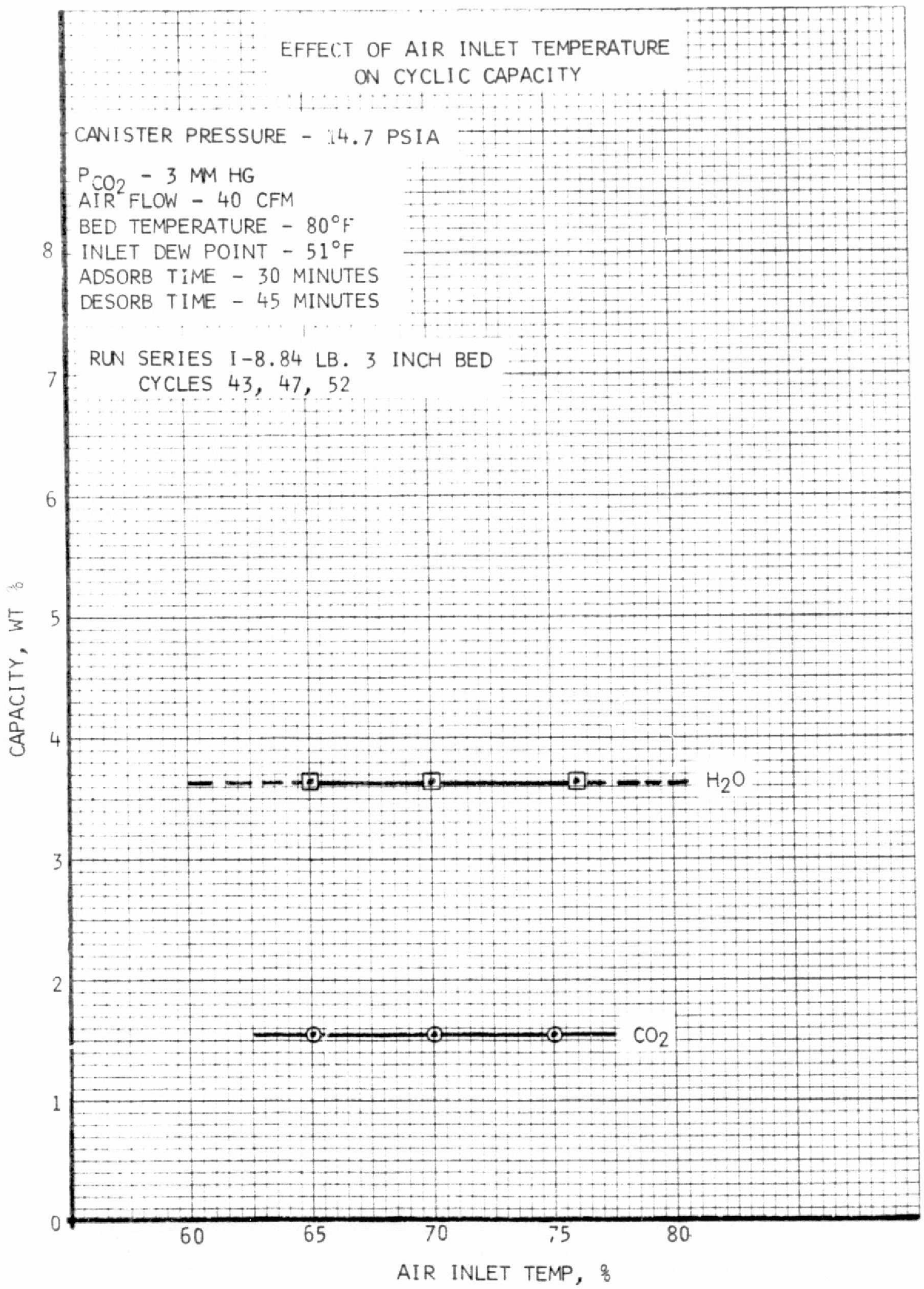


FIGURE 11

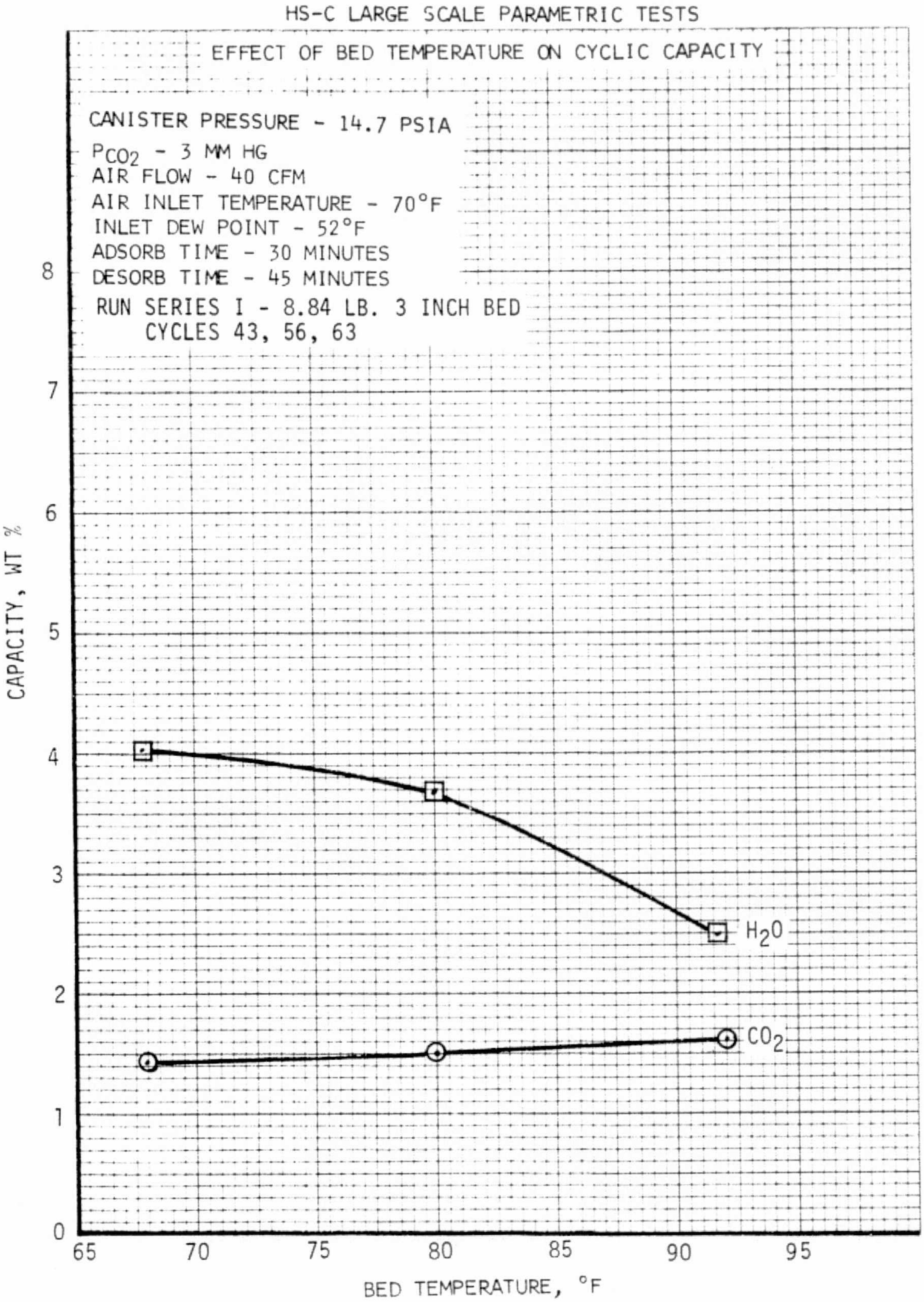

HS-C LARGE SCALE PARAMETRIC TESTS
EFFECT OF BED TEMPERATURE ON CYCLIC CAPACITY
CANISTER PRESSURE - 14.7 PSIA
P_{CO_2} - 3 MM HG
AIR FLOW - 40 CFM
AIR INLET TEMPERATURE - 70°F
INLET DEW POINT - 52°F
ADSORB TIME - 30 MINUTES
DESORB TIME - 45 MINUTES
RUN SERIES I - 8.84 LB. 3 INCH BED
CYCLES 43, 56, 63
CAPACITY, WT %
0
1
2
3
4
5
6
7
8
H_2O
CO_2
65
70
75
80
85
90
95
BED TEMPERATURE, °F

FIGURE 12

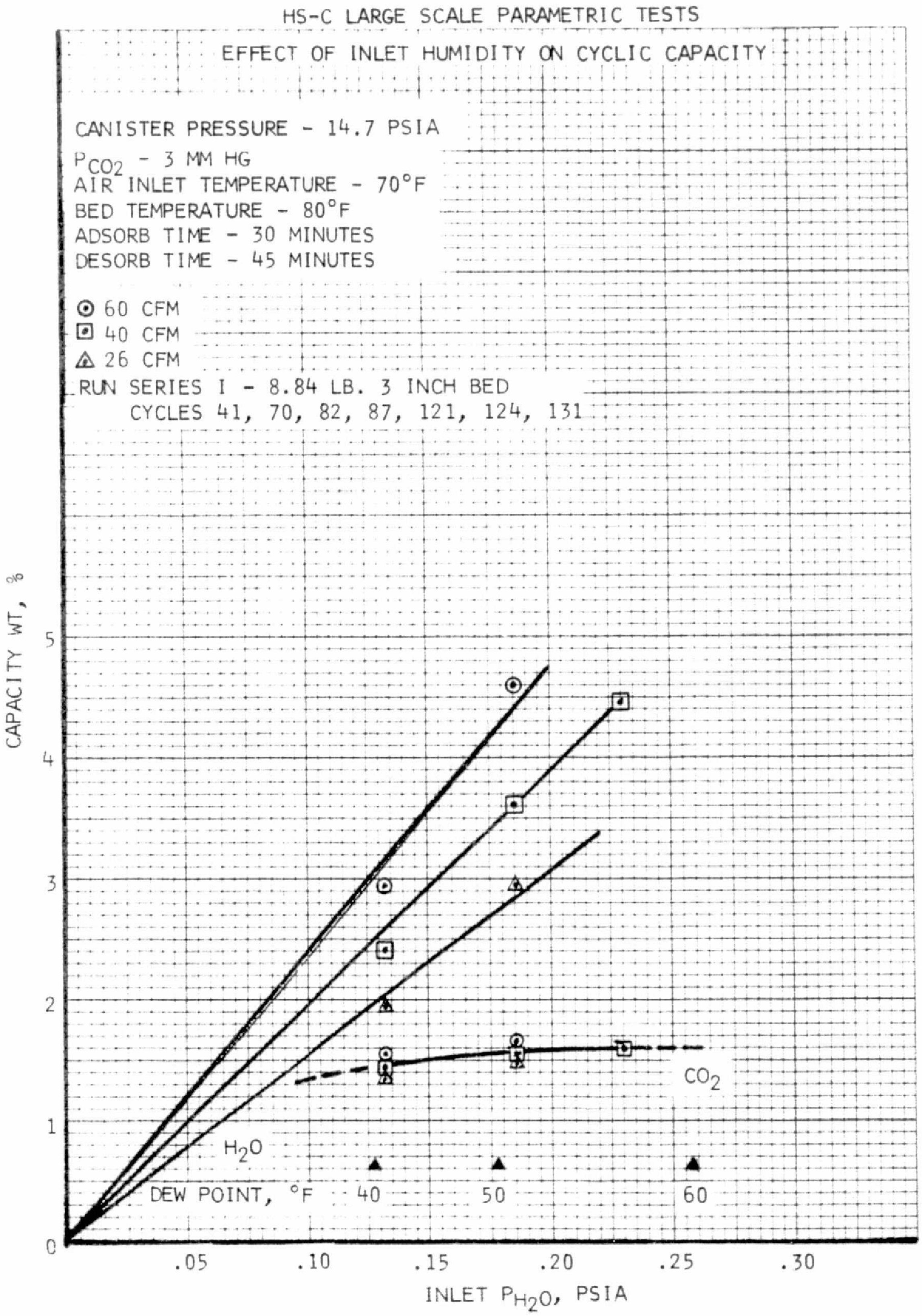

HS-C LARGE SCALE PARAMETRIC TESTS
EFFECT OF INLET HUMIDITY ON CYCLIC CAPACITY
CANISTER PRESSURE - 14.7 PSIA
P_{CO_2} - 3 MM HG
AIR INLET TEMPERATURE - 70°F
BED TEMPERATURE - 80°F
ADSORB TIME - 30 MINUTES
DESORB TIME - 45 MINUTES
60 CFM
40 CFM
26 CFM
RUN SERIES I - 8.84 LB. 3 INCH BED
CYCLES 41, 70, 82, 87, 121, 124, 131
CAPACITY WT, %
0
1
2
3
4
5
CO_2
H_2O
DEW POINT, °F
40
50
60
.05
.10
.15
.20
.25
.30
INLET P_{H_2O}, PSIA

FIGURE 13

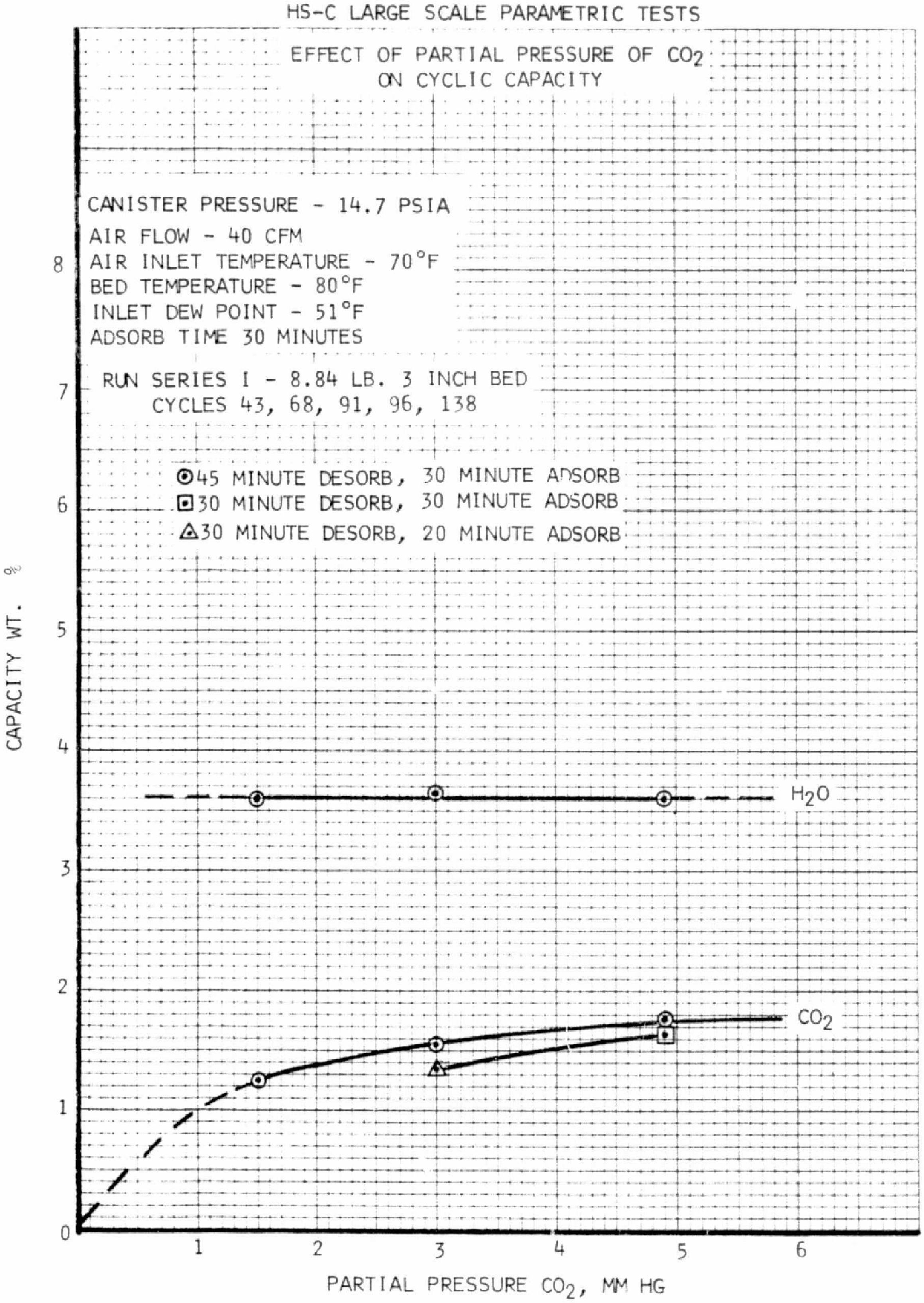

HS-C LARGE SCALE PARAMETRIC TESTS
EFFECT OF PARTIAL PRESSURE OF CO_2
ON CYCLIC CAPACITY
CANISTER PRESSURE - 14.7 PSIA
AIR FLOW - 40 CFM
AIR INLET TEMPERATURE - 70°F
BED TEMPERATURE - 80°F
INLET DEW POINT - 51°F
ADSORB TIME 30 MINUTES
RUN SERIES I - 8.84 LB. 3 INCH BED
CYCLES 43, 68, 91, 96, 138
⊙ 45 MINUTE DESORB, 30 MINUTE ADSORB
⊡ 30 MINUTE DESORB, 30 MINUTE ADSORB
△ 30 MINUTE DESORB, 20 MINUTE ADSORB
H_2O
CO_2
CAPACITY WT. %
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
PARTIAL PRESSURE CO_2, MM HG

FIGURE 14

HS-C LARGE SCALE PARAMETRIC TESTS

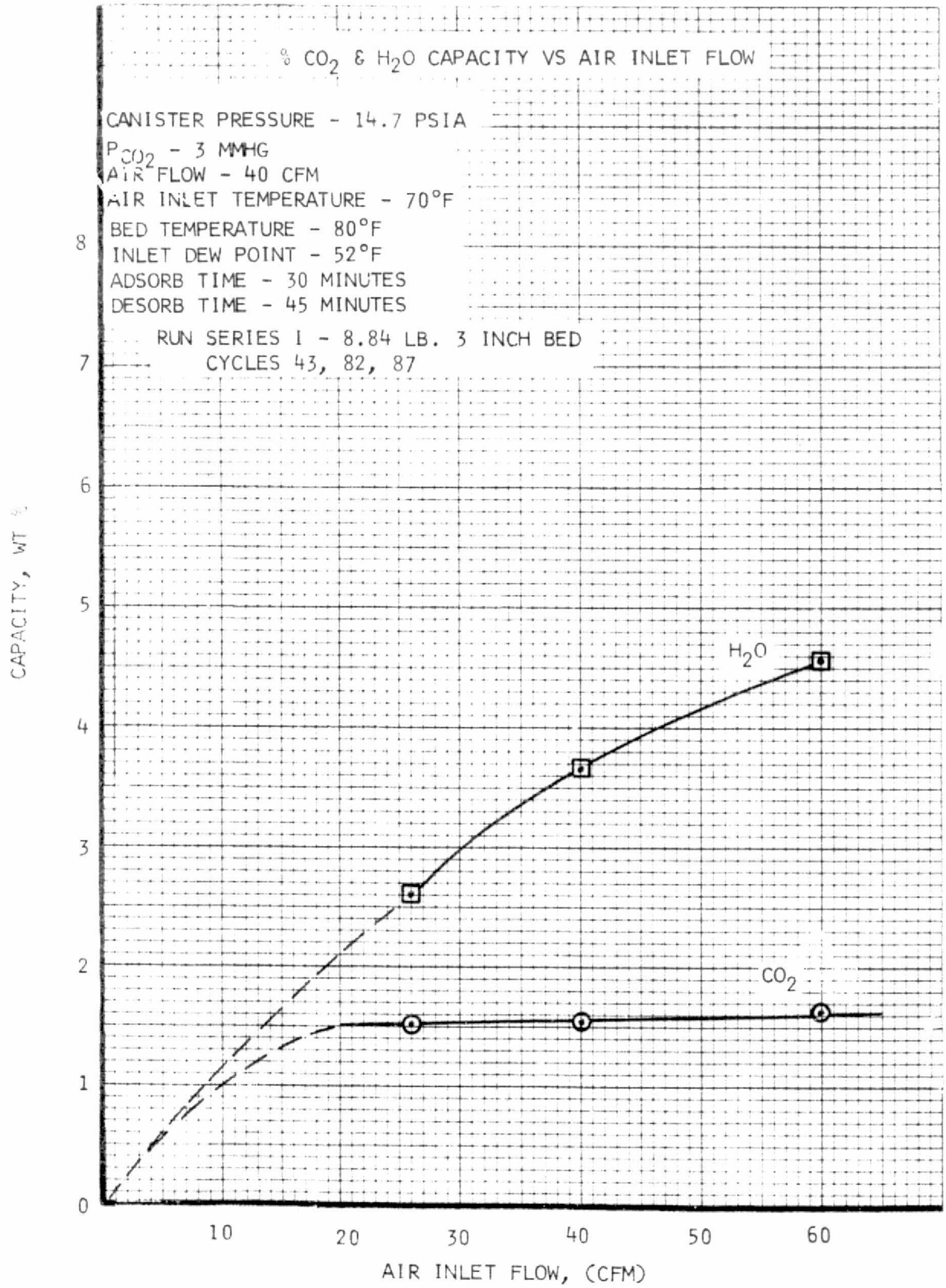


FIGURE 15

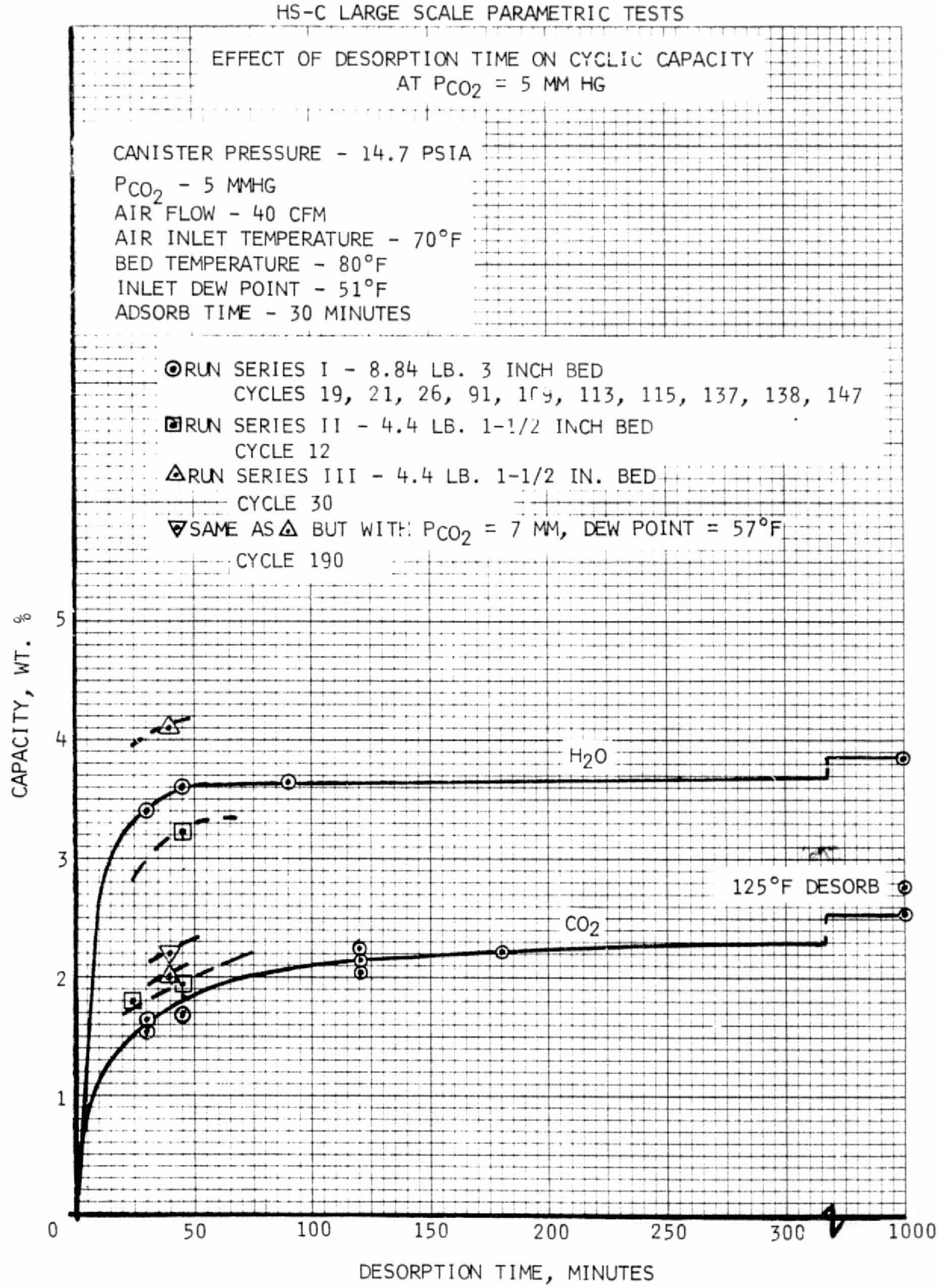

HS-C LARGE SCALE PARAMETRIC TESTS
EFFECT OF DESORPTION TIME ON CYCLIC CAPACITY
AT P_{CO_2} = 5 MM HG
CANISTER PRESSURE - 14.7 PSIA
P_{CO_2} - 5 MMHG
AIR FLOW - 40 CFM
AIR INLET TEMPERATURE - 70°F
BED TEMPERATURE - 80°F
INLET DEW POINT - 51°F
ADSORB TIME - 30 MINUTES
RUN SERIES I - 8.84 LB. 3 INCH BED
CYCLES 19, 21, 26, 91, 109, 113, 115, 137, 138, 147
RUN SERIES II - 4.4 LB. 1-1/2 INCH BED
CYCLE 12
RUN SERIES III - 4.4 LB. 1-1/2 IN. BED
CYCLE 30
SAME AS △ BUT WITH P_{CO_2} = 7 MM, DEW POINT = 57°F
CYCLE 190
CAPACITY, WT. %
H_2O
125°F DESORB
CO_2
0
1
2
3
4
5
50
100
150
200
250
300
1000
DESORPTION TIME, MINUTES

FIGURE 16

HS-C LARGE SCALE PARAMETRIC TESTS
EFFECT OF DESORPTION TIME ON CYCLIC CAPACITY

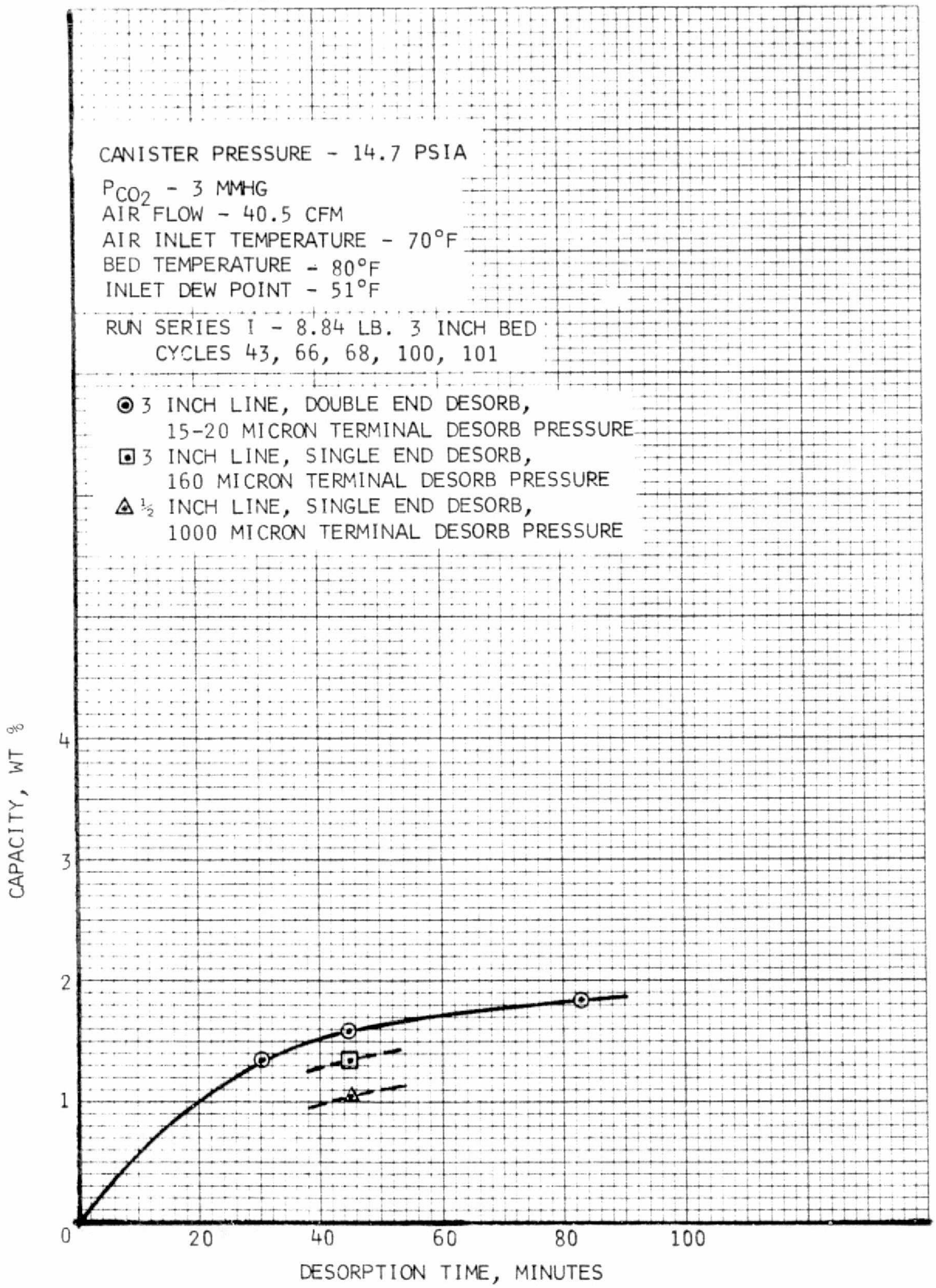


FIGURE 17

DESIGN CONCEPT DEVELOPMENT

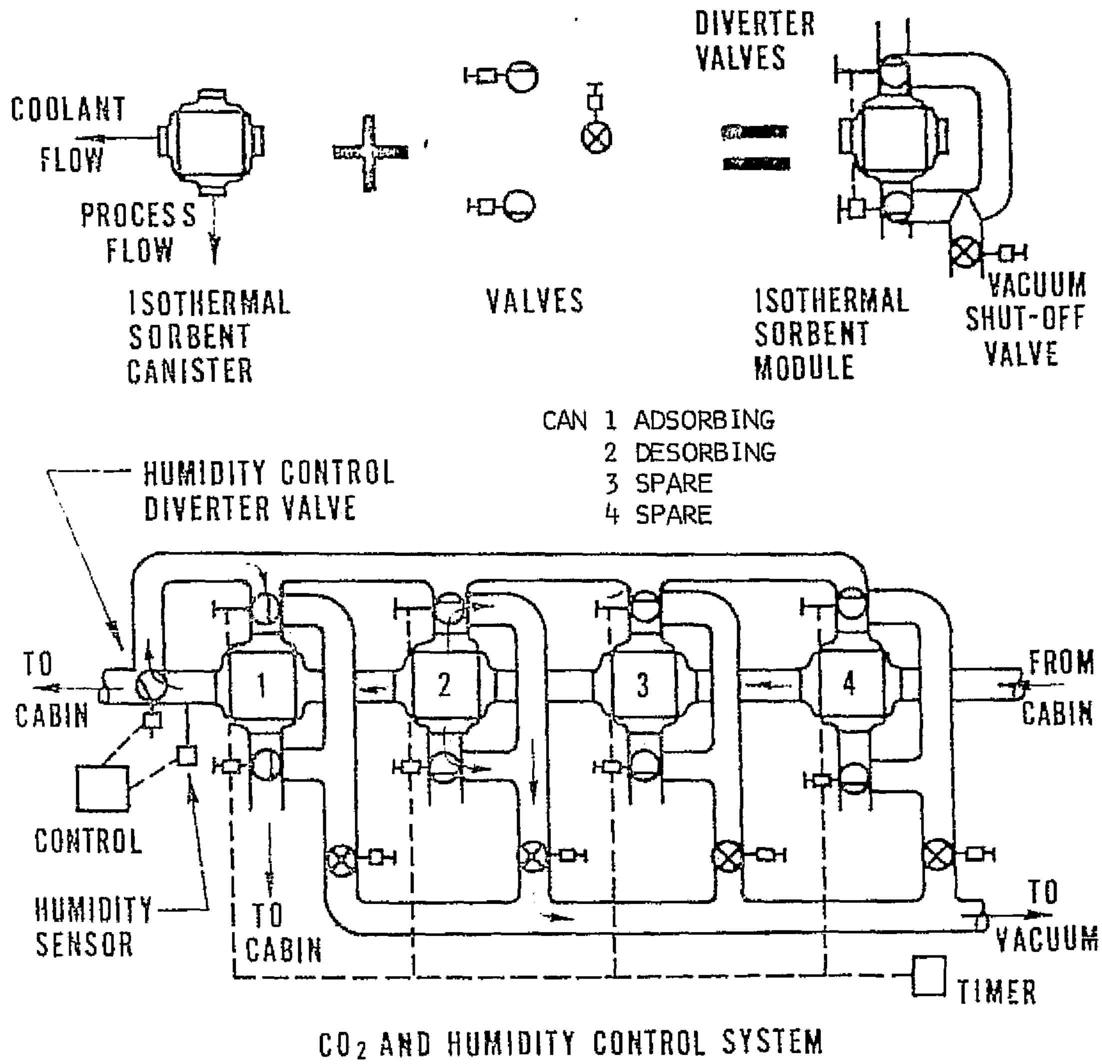
A final objective of the contract was to develop a system design concept applicable to the Space Shuttle. Figure 18 shows the proposed configuration of an HS-C system for the Space Shuttle. Four canisters are used, of which two are spares.

Incoming cabin air serves as a heat transfer fluid, exchanging heat between adsorbing and desorbing canisters, which are specially designed plate-fin heat exchangers. The air then enters the adsorbing canister and is exhausted to the cabin. The desorbing canister is valved to space vacuum through each end of the canister.

It was found that water capacity was controlling for the Shuttle application, i.e., CO_2 levels were held within tolerance if the bed was sized to remove the generated water vapor. Further, the cabin humidity can be controlled by varying air flow while the carbon dioxide removal rate is relatively unaffected. The results of the large scale tests (Series I) were transferred into water capacity-gas flow-dew point curves and processed by a Hamilton Standard optimizing design program which optimized the entire CO_2 and water removal system, including fan, pump, and radiator designs. A similar optimization was run for a LiOH system. Results are shown in Figures 19 and 20.

The lower expendable weight penalty associated with the HS-C system is shown by Figure 19. The weight differential between HS-C and the conventional LiOH condenser system varies from 200 pounds at a 7-day mission to almost 750 pounds at a 30-day mission.

In Figure 20, the effect of crew size is shown. The weight optimized HS-C system maintains a lower cabin dew point than the LiOH system. This permits the cabin air heat exchanger to operate with lower coolant temperatures without condensing. It also minimizes the need for coolant line insulation to prevent condensation in undesirable locations. As expected, the weight advantage of HS-C increases somewhat with crew size, but not as dramatically as with mission duration. The basic weight advantage would increase with improved water capacity, since in all cases the HS-C bed size was determined by the required water capacity as opposed to CO_2 removal requirements. The goals established at the inception of this program of 4% water and 2% CO_2 capacity should be modified since they do not produce the minimum weight HS-C system. TEPA based materials (Figure 1) for instance, have 50% greater water capacity than the PEI based material used for this program.



SORBENT ARRANGEMENT AND CONTROL

FIGURE 18

Other advantages of HS-C include the "forget it" aspect between flights -- no replacement is necessary and poisoning constituents are not present in the normal atmosphere. The ease of ground regeneration through dry gas purge is also convenient, and the simplicity of the system, which lacks liquid lines of any sort and has no connections required beyond space vacuum and electricity, is very appealing from a design and reliability viewpoint.

The following pages discuss in more detail the material presented in the summary report.

SYSTEM COMPARISON HS-C AND LiOH - CONDENSER
MISSION LENGTH-DAYS

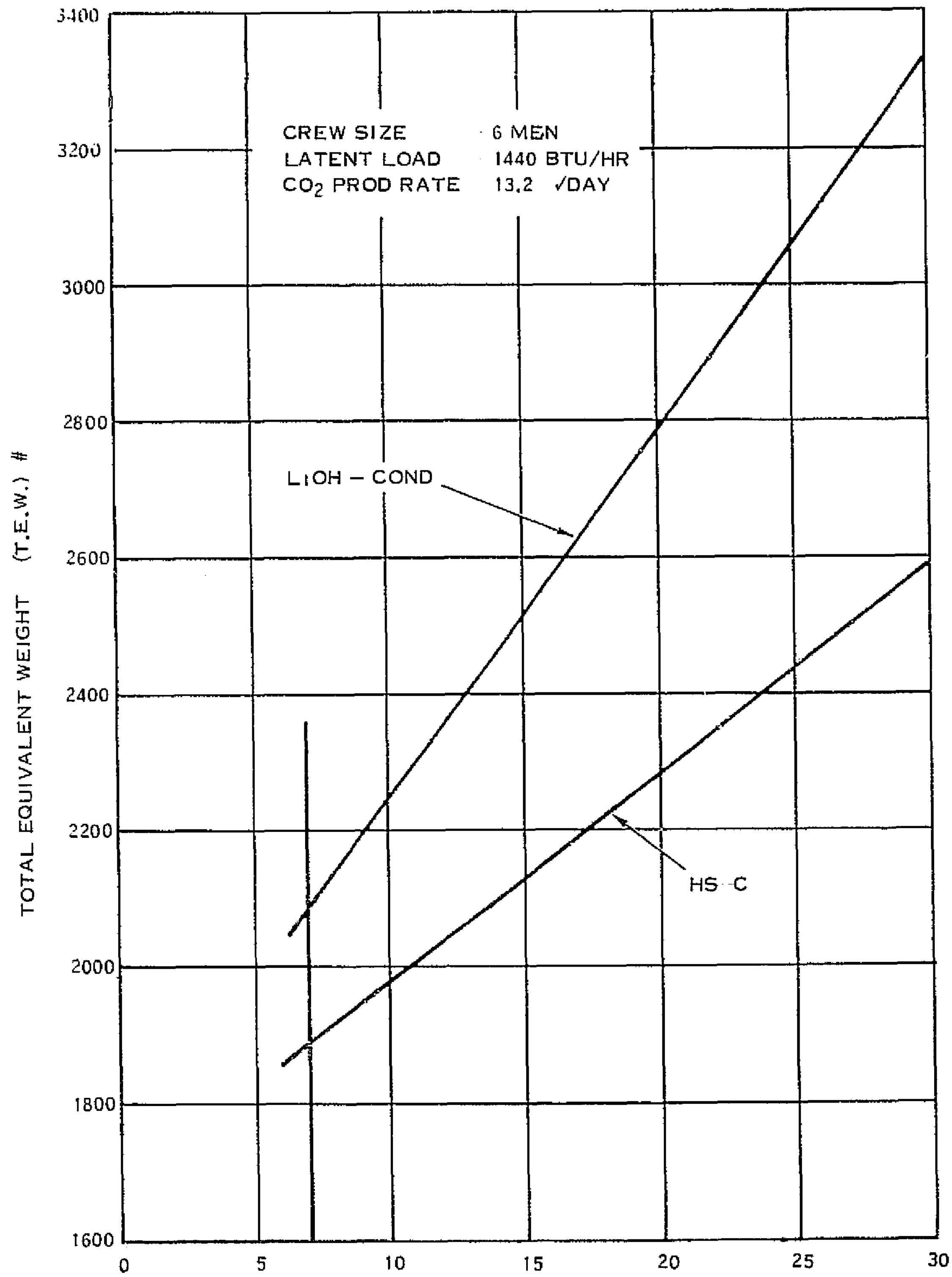


FIGURE 19

SYSTEM COMPARISON HS-C AND LiOH - CONDENSER
CREW SIZE

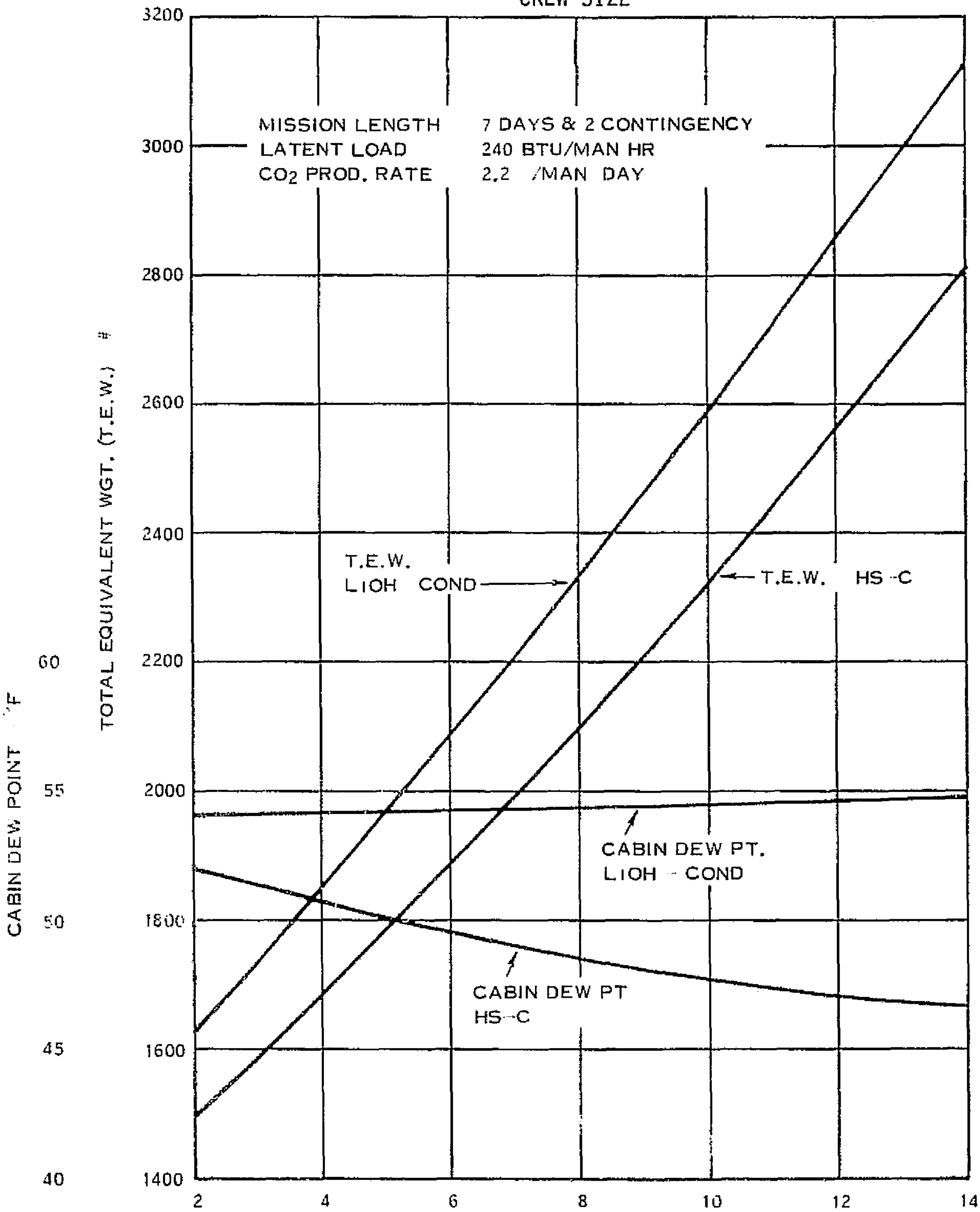


FIGURE 20

MATERIAL SELECTION AND PROPERTIES

SMALL SCALE APPARATUS DESCRIPTION

Objectives and Capabilities

Development of the HS-C material has required a means for fast evaluation of the CO_2 and water capacity of small samples. The "Sorbent Evaluator" used for small scale tests was designed for this task. It evaluated 5 cc (about 2.0 gm HS-C) samples with a precision of ±5% under fixed conditions. The apparatus is also capable of testing larger quantities of sorbent (limited by inlet flow of about 1 cfm), and can desorb under vacuum conditions (as for the Space Shuttle) or when heated at a mild vacuum (as for the Space Station).

The Sorbent Evaluator is a "two-can" system; i.e., it tests two samples at once, one adsorbing while the other desorbs. This arrangement is especially useful when comparison with a standard material is desired, for both beds see precisely the same conditions.

HS-C generally takes only three adsorption-desorption cycles to achieve a cyclical steady state. At the test condition of 45 minute absorb - 45 minute desorb generally employed, evaluation of a material therefore took about 5 hours.

Evaluation of performance was by periodic analysis by gas chromatograph of feed and effluent streams. The chromatograms were taken at three minute intervals and recorded closely together so that by connecting the peak heights a "breakthrough curve" was formed which was then graphically integrated to find CO_2 or water removal efficiency. Weight capacity was then calculated from inlet flow rate, inlet CO_2 partial pressure, and bed weight.

Apparatus Description

Main Flow

Figure 21 shows the rig schematic, simplified by omission of certain unused plumbing.

Atmospheric air entered the flow regulator assembly (a), where it was reduced to the rig pressure of about 28 in Hg. After metering by rotameter (b), the air passed over room temperature water in the humidifier (c), and thus approached room temperature in dew point. The humidified air was cooled

SORBENT EVALUATOR

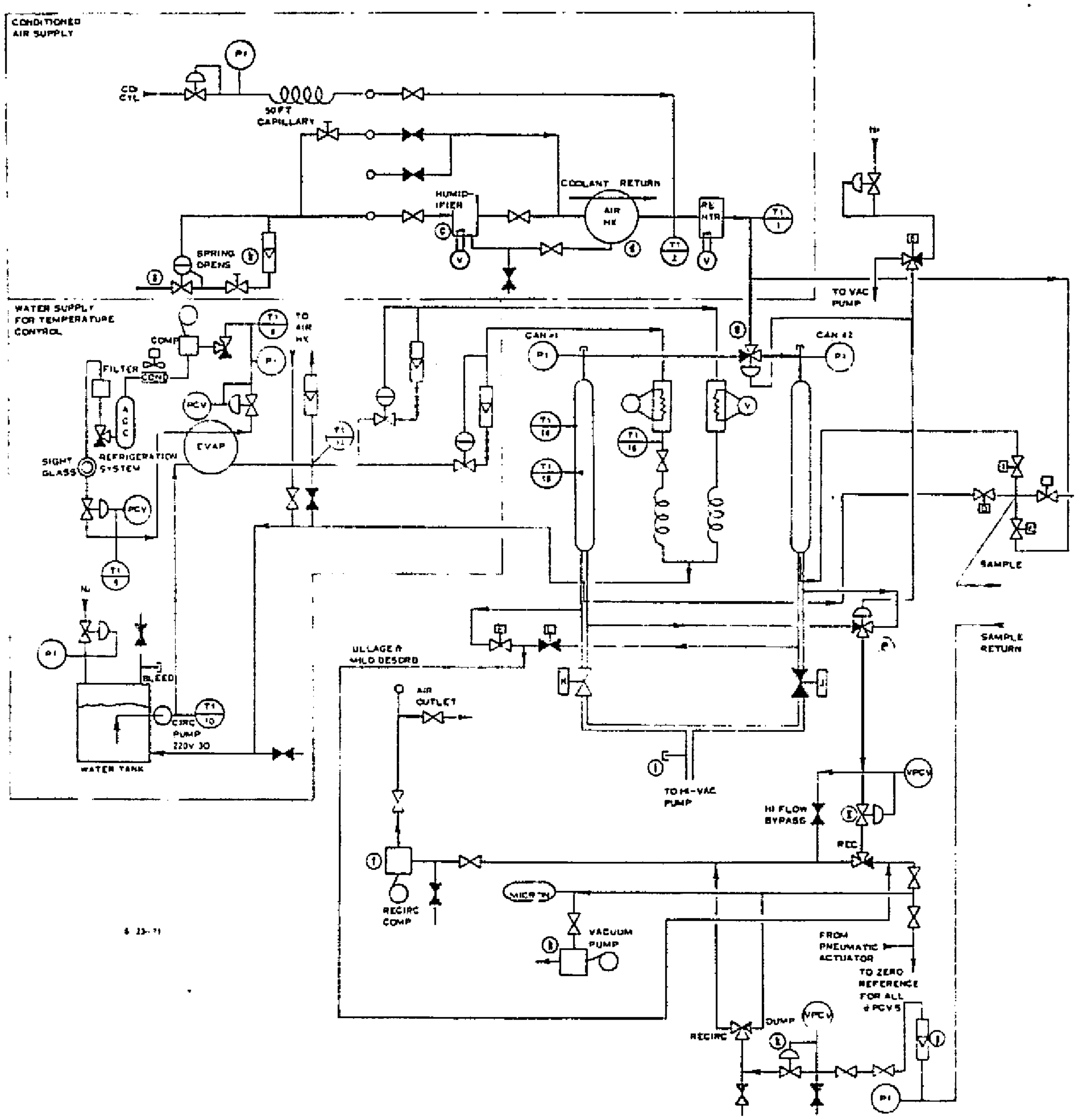


FIGURE 21

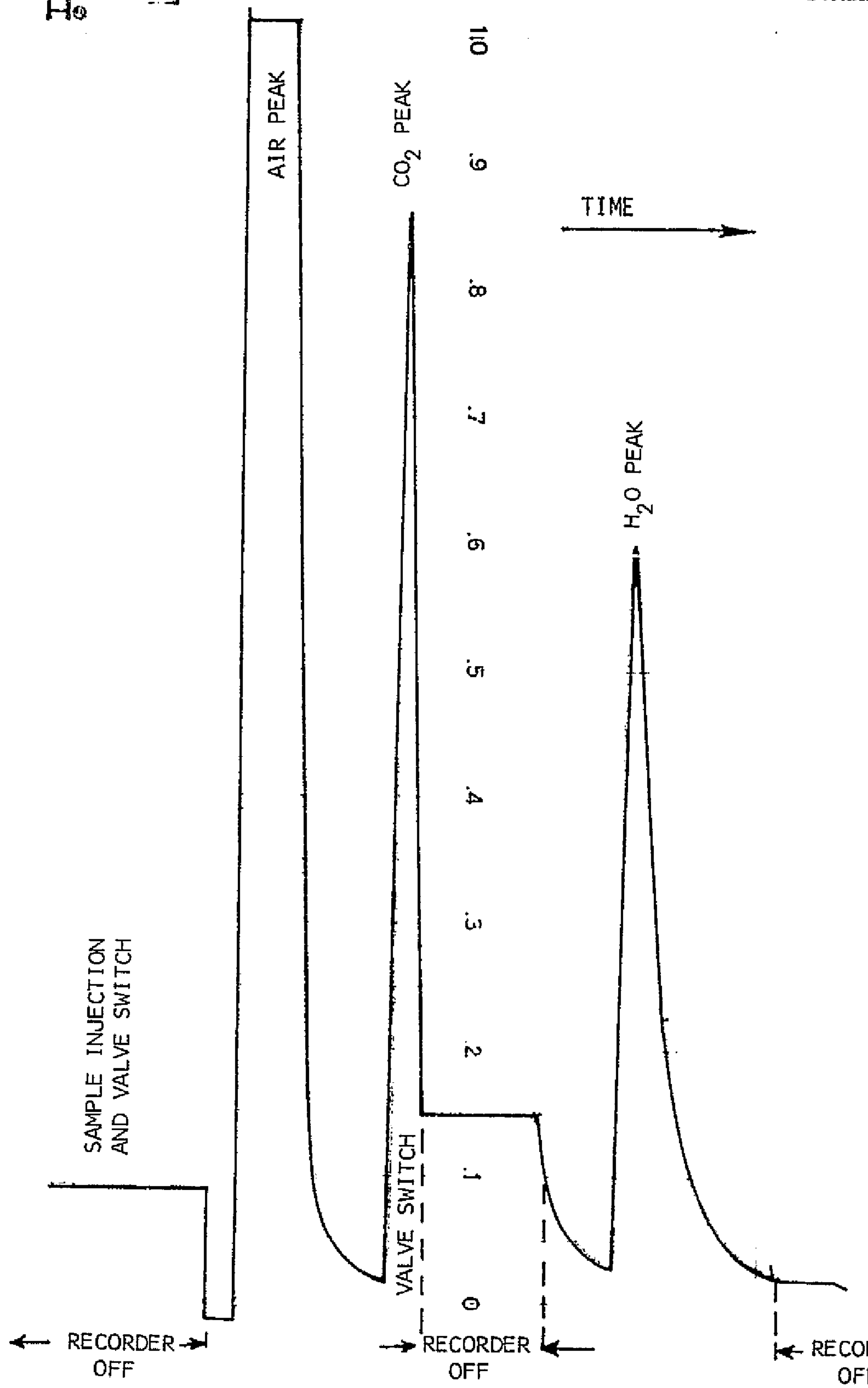
in the oversized air heat exchanger (d) to the required dew point as set by the cooling water temperature which was controlled by the refrigeration system. Carbon dioxide was metered into the air stream from a pressurized cylinder using a 50 foot capillary tube and pressure reducing regulator. At the low air flows used for this work (500 ml/min) the air was reheated to room temperature (about 70-75°F) by the uninsulated piping leading to the first cycling valve (f). With both valves (f) as shown, the air flowed through can #2, and in the alternate position the flow was through can #1. After leaving the second valve (f), the air was released to the diaphragm pump (f) by absolute pressure regulator (g) so as to maintain proper rig pressure (28 in. Hg). When can #2 (or #1) was desorbing, ullage was pumped out through a special vacuum pump (h) when solenoid valve (F) or (L) was activated. When the ullage was gone, the timed cycle closed these valves and opened valves (K) or (J) to desorb the bed using a larger vacuum system (i), which utilized a diffusion pump.

Sampling

A bed effluent sample was withdrawn from the canister outlet during adsorption by appropriately energizing solenoid valve D or I. At the end of each adsorption the feed was sampled through a solenoide valve E. The sample flow passed through the chromatograph sampling valve and then back through the sample rotameter. Sample flow rate was controlled by a metering valve leading to a fixed lower pressure set by a back pressure regulator. Sample gas leaving this regulator was returned to atmospheric pressure by diaphragm pump (f). Sample analysis, by gas-liquid chromatograph, produced an analysis every three minutes.

To obtain the three minute cycle and proper peak heights from the gas chromatograph a special column switching timer system was used. The sampling valve was automatically actuated every three minutes, introducing a small (1/16 ml) test sample into the helium carrier gas, which was regulated to 40 psig. The helium flowed through a 12 foot column filled with Porapak Q and an eight foot tube filled with Porapak T, both held in an oven at 72°C. After 1-1/2 minutes the air and CO_2 peaks had emerged, and then the second column was valved out and eight feet of Porapak Q substituted to permit the water peaks to occur at about 2-1/2 minutes (rather than 5 minutes). Since the valve switching produced false peaks, the detector signal was switched out except when the actual peaks were seen by the thermal conductivity detector[1] on the Varian chromatograph. A typical resultant chromatogram is shown in Figure 22. A series of these, three minutes apart, produces the test data for a given cycle (Figure 23).

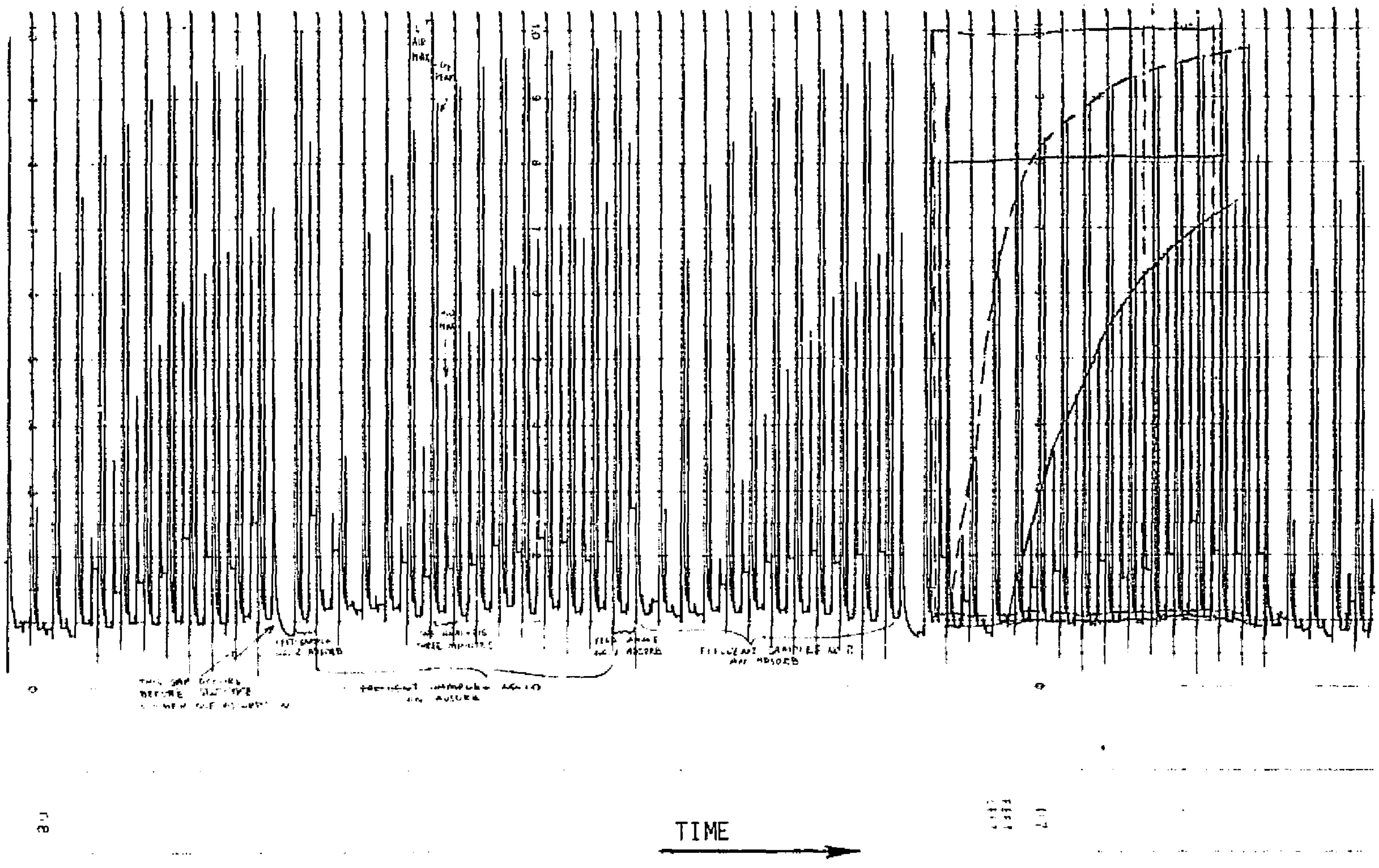
[1]Current was 200 ma.



SMALL SCALE TESTS
SAMPLE CHROMATOGRAM (ONE ANALYSIS)
CHART SPEED 2 DIVISIONS/MINUTE

FIGURE 22

FIGURE 23



CYCLIC TEST DATA
SMALL SCALE APPARATUS

Test Canisters

The canisters were constructed of Swagelok fittings and 1/2 inch stainless steel tubing with appropriate screens to hold the HS-C in place. No effort was made to fill the entire volume between screens with HS-C.

Canister Temperature Control

Canisters were maintained at a constant temperature by water coils wrapped around them. A carefully metered flow of water from the cooling system was heated electrically to the desired temperature (typically 75°F) and then returned to the water storage reservoir.

Timing Sequence

Actuation of the cycled valves was by an electrical cam timer. Valves (e) were energized pneumatically, using nitrogen pressure. The cycling sequence was as follows:

Step	Valves (e)	Valves (F,L)	Valves (I, D, or E)	Valves (J and K)
1-Start Adsorb Can #2	as shown	closed	closed	closed
2-Ullage dump	as shown	as shown	open/closed/closed	closed
3-Adsorb Can #2, Desorb #1	as shown	closed	open/closed/closed	as shown
4-Feed Sample	as shown	closed	closed/closed/open	closed
5-Start Adsorb Can #1	reversed	closed	closed	closed
6-Ullage dump	reversed	reversed	closed/open/closed	closed
7-Adsorb Can #1, Desorb #2	reversed	closed	closed/open/closed	reversed
8-Feed Sample	reversed	closed	closed/closed/open	closed

Calibration

Most of the temperature measurements from the Sorbent Evaluator were from uncalibrated copper-constatan thermocouples. These were observed to read room temperature accurately when first made.

Measurements important to the calculations of capacity were:

1. System Pressure
2. Inlet Gas Flow Rate
3. Sample Weight
4. Adsorption Time
5. Inlet and Outlet CO_2 and Water Vapor Partial Pressure

These were calibrated as follows.

System Pressure

A single 30 in. Hg absolute reference pressure gauge was used for this measurement. It was checked at zero pressure (during desorption) and atmospheric pressure (against a mercury column) and was found correct within ±1 division or ±0.1 in. Hg.

Inlet Gas Flow Rate

A wet test meter was placed at the rig inlet for rotameter calibration. The wet test meter was at atmospheric pressure and the rotameter was at the usual rig pressure of 28 in. Hg. Data, calculations and factory calibration are shown in Figure 24 along with the resultant calibration curve.

Sample Weight

Just after preparation of HS-C, a 10 ml sample was quickly weighed using a tared 10 ml graduate. The resultant density was noted and used in the calculations. A 5 ml sample was then used for all evaluations, eliminating the effect of weight gains during transfer and storage due to adsorption.

Adsorption Time

Adsorption time was measured from the recorder chart. Capacities were calculated for both the first 30 minutes of adsorb and for the full 45 minutes.

Inlet and Outlet CO_2 and Water Vapor Partial Pressure

Carbon Dioxide.- The chromatographic standard gas was available from earlier programs. Its calibration was checked using "spray" cans of certified calibration at atmospheric pressure. The data and calibrations are shown in Figure 25. After the standard gas mixture was calibrated the chromatographic columns were changed, and a new single point recalibration was made using the

Hamilton Standard
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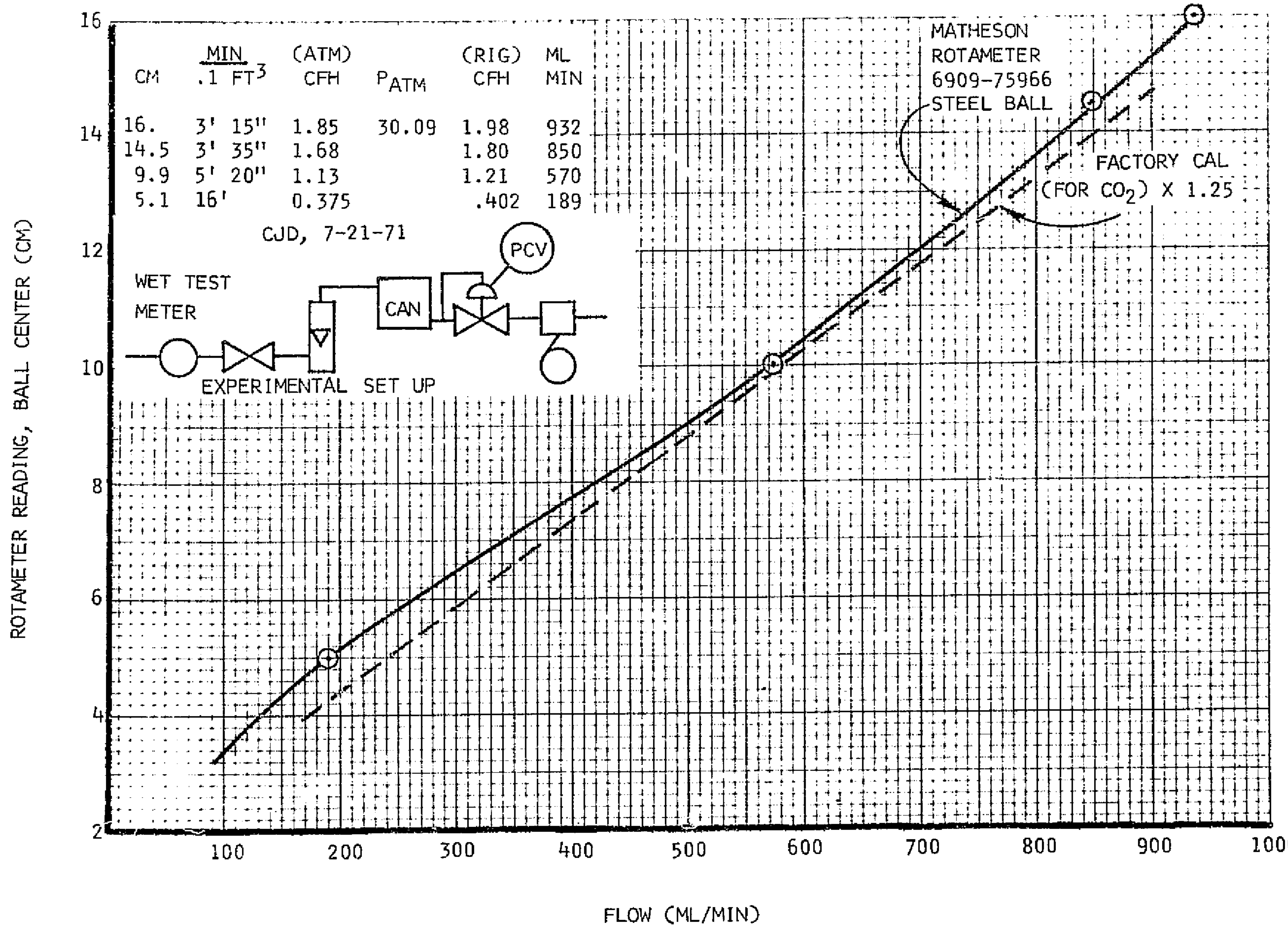
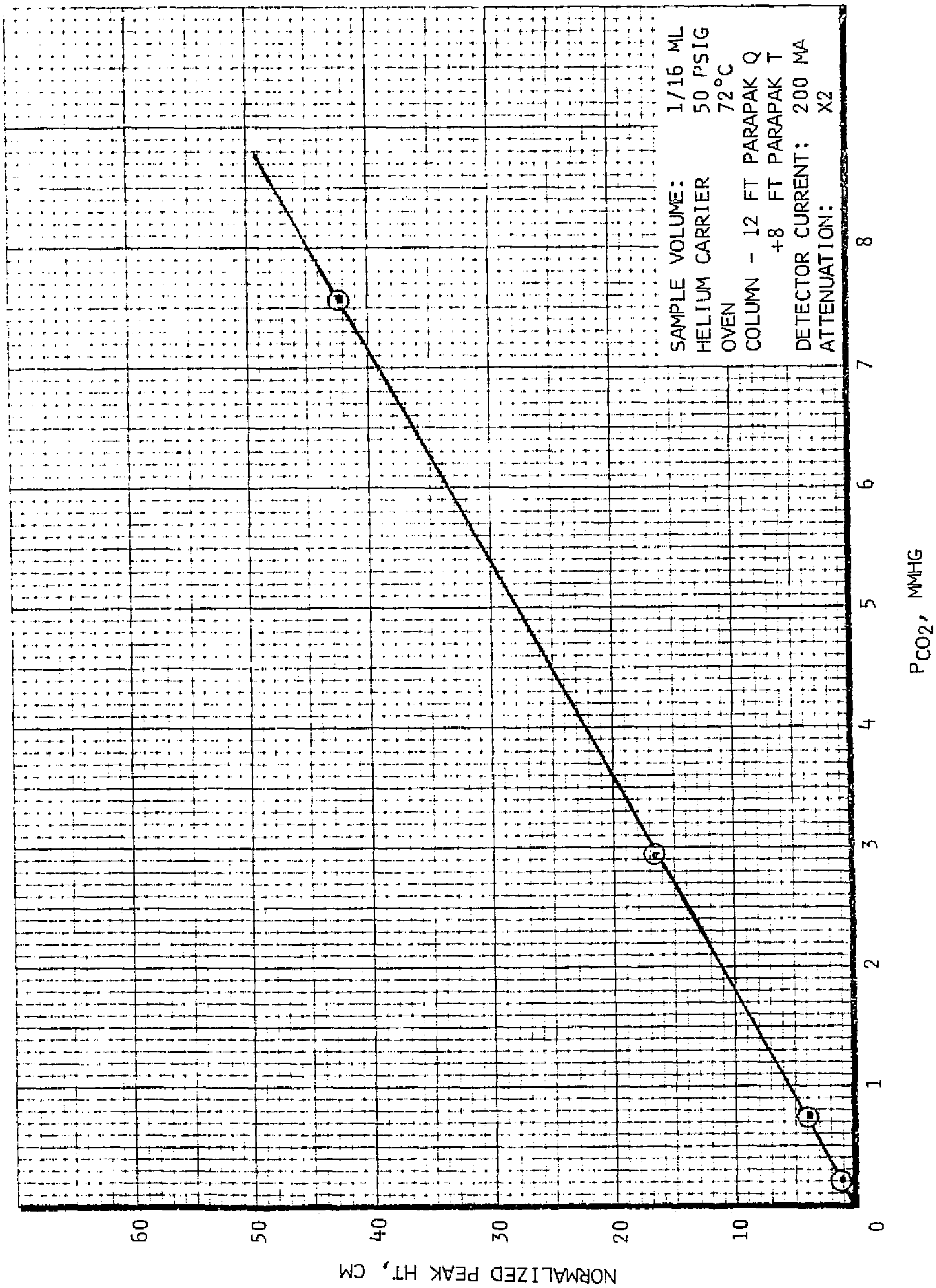


GAS FLOW CALIBRATION
SMALL SCALE TESTS

FIGURE 24



SMALL SCALE TESTS
CO_2 CALIBRATION
GAS CHROMATOGRAPH

FIGURE 25

standard gas mixture. Periodic recalibration assured consistent data throughout the experimental program.

The calibration gas was introduced into the apparatus via the fourth (unmarked) sample solenoid valve. The calibrated gas flow rate was adjusted so that the sample flow rate and (downstream) pressure were identical to the rig normal samples. Calibrations were generally stable, drifting perhaps 5% at most in a month. The most recent calibration always was used for an evaluation.

Water Vapor:- Chromatographic calibrations were made with a Cambridge Dew Point hygrometer, but the accuracy of the instrument available for the small scale tests were questionable even though it was calibrated according to the manufacturer's recommendations. It was decided to ignore this instrument and use conservative data by assuming that the inlet dew point is equal to the lowest water temperature in the dew point condenser (Figure 21, TI-11). A calibration curve prepared in this fashion is shown as Figure 26.

Calculations

Nomenclature

V = air flow rate ml/min at rig P

P_i = Partial Pressure species i

H_i = Chromatographic peak ht species i

P_{ical}, H_{ical} = calibration partial pressure and peak ht

P_T = rig pressure

x_i = mol fr species i

V_{iR} = species i flow removal, ml/min at rig pressure

V_i = species i flow, ml/min at rig pressure

W_i = wt flow species i, gms/min

P_T = rig pressure, absolute units

P_{atmstd} = pressure std atmosphere, same unit as P_T

M_i = molecular wt species i

T = flow temp. °C

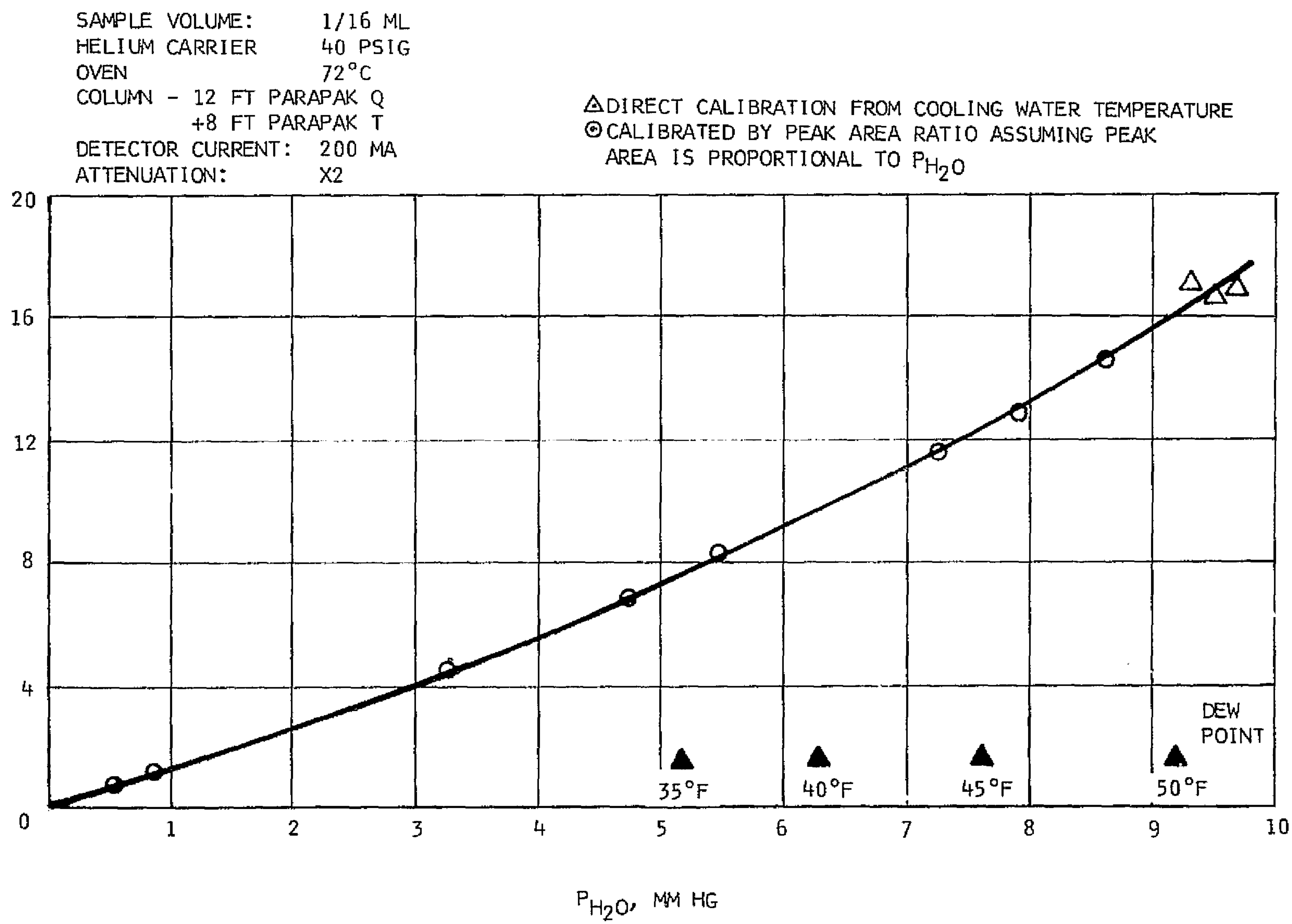


FIGURE 26

SMALL SCALE TESTS
H_2O CALIBRATION
GAS CHROMATOGRAPH

$$R = \frac{82.06 \text{ atm cm}^3}{\text{gm mol } ^\circ K}$$

ω_s = wt sample, gms

υ_s = volume sample, ml

C_{wt} = capacity wt %

C_{vol} = capacity gms species i/1000 ml sample

CO_2 or H_2O partial pressure in the feed is:

$$P_i = \frac{H_i \, P_{ical}}{H_{ical}}$$

Expressed as mol fraction:

$$x_i = \frac{P_i}{P_T} = \frac{H_i \, P_{ical}}{P_T \, H_{ical}}$$

The flow rate of CO_2 or H_2O flowing to the canister is then:

$$V_i = x_i \, V = \frac{V}{P_T} \frac{H_i \quad P_{ical}}{H_{ical}}$$

E_i is the removal efficiency for the i species, so the volumetric gas adsorption rate is:

$$V_{iR} = \frac{E_i \, V_i}{100} = \frac{E_i}{100} \frac{V \quad H_i \, P_{ical}}{P_T \, H_{ical}}$$

and the weight flow rate adsorbed is:

$$w_i = \frac{P_T}{100 \, P_{atmstd}} \frac{V_{iR}}{R} \frac{M_i}{(273 + T)} = \frac{M_i}{100 \quad P_{atmstd}} \frac{E_i}{R} \frac{V \quad H_i \quad P_{ical}}{(273 + T) \, H_{ical}}$$

Where the perfect gas law is expressed as:

$$\frac{PV}{P_{atmstd}} = \frac{W_i}{M_i} RT$$

From this expression a volume capacity and a weight capacity were calculated for the adsorption time period:

$$C_{vol} = \frac{W_i t}{\upsilon_s} \; 1000$$

$$C_{wt} = \frac{C_{vol} \;\; \upsilon_s}{10 \; W_s}$$

Assuming 25°C feed, for CO_2:

$$C_{vol} = 2.367 \times 10^{-5} \; \frac{H_{CO_2cal} \;\; P_{CO_2} \; E_{CO_2} \;\; Vt}{H_{CO_2cal} \qquad \upsilon_s}$$

where

P_{CO_2cal} is partial pressure of CO_2 at calibration

H_{CO_2cal} is peak ht at calibration

H_{CO_2} is inlet peak ht in same units

E_{CO_2} is CO_2 removal efficiency in percent

V is air flow, ml/min at rig pressure

t is time of sorption, min

ω_s is sample wt, gms

υ_s is sample volume, ml

For water vapor:

$$C_{vol} = 0.962 \times 10^{-5} \; \frac{E_{H_2O} \; Vt \; P_{H_2O}}{\upsilon_s}$$

$$C_{wt} = \frac{C_{vol}}{10} \; \frac{\upsilon_s}{\omega_s}$$

where E_{H_2O} = removal efficiency for H_2O in percent

V = air flow, ml/min at rig pressure

t = time of sorption, min

P_{H_2O} = partial pressure of water vapor in feed, mmHg

υ_s = volume of sample, ml

ω_s = sample wt, gms

Both calculations depend on the linearity of the chromatographic peak heights with composition. Examination of Figures 25, 26 show that the CO_2 composition is linear with peak heights but the water is not. The maximum non-linearity introduces a maximum error of about 10% into an individual analysis, with zero error at zero concentration or near the feed concentration. The probable error in removal efficiency is about +5%, insignificant and equivalent in effect to a +1/2°F error in inlet dew point.

Calculation Sheet.- The Sorbent Evaluator calculation sheet (Figure 27) was used for all runs. Five calculations were handled on one sheet, along with all data except the actual breakthrough curves. A sample calculation is given below, keyed to letters (a-q) to aid in the description.

Sample and run identification were first noted (a). Then the rotameter reading and its calibrated flow rate (b), and then a conversion factor was applied to give flow in ml/min (or liters/min) (c). Adsorption and desorption conditions were next noted (d). Then the CO_2 feed chromatographic peak heights (e), calibration height (f), P_{CO_2} of the calibration gas (in mm Hg at rig pressure) (g), and a factor (h) (when using other than standard chromatographic attenuation) were recorded. Similarly for water vapor the feed peak height (i) was noted and equated with the dew point which generally was taken as the cooling water temperature to the dew point heat exchanger (j). The corresponding P_{H_2O} in mm Hg was then noted (k) from graph or table.

The removal efficiency was then calculated (l) by tracing on good tracing paper the breakthrough curves for water and CO_2 and applying the feed composition as shown in Figure 28. Using an analytical balance the total area, bypass area and adsorbed area were determined, enabling calculation of removal efficiency by ratio.

The factors determined above along with sample weight and volume were then inserted in the final equation for CO_2 (m) and H_2O (n), leading to a volume capacity (p) and a weight capacity (q).

MATERIAL DESCRIPTION

HS-C is a proprietary sorbent made from commercially available raw materials. It consists of small (1/2 mm) spheres of a polymeric macroreticular substrate which is coated with a thick, polymeric, liquid sorbent made from low molecular weight amines.

The substrate is Rohm & Haas XAD-7 sorbent. It is processed at Hamilton Standard by sieving, by washing with deionized distilled water and analytical grade methyl alcohol, and then coated with the liquid sorbent, Dow PEI-18 and dried. Ultra-pure water is needed for the washing procedure since traces of copper adversely affect adsorptive performance.

Hamilton U
Standard A®

CR-115568
SVHSER-6040

SORBENT EVALUATOR CALCULATION SHEET

USE FLOW IN LITERS/MIN OR ML/MIN, WT IN KG. GM, VOL IN LITERS ML

SAMPLE IDENTIFICATION		RAW FLOW RDG	CAL FLOW	FACTOR 28.3 FOR CFM 472 FOR CFH	FLOW LITERS/MIN ML/MIN	ABSORPTION PRESS. IN HG	ABSORPTION AIR INLET T F	ABSORPTION WATER TEMP F	DESORPTION WATER TEMP F	DESORPTION PRESS. IN.HG OR μ	DESORPTION TIME MIN	ABSORPTION TIME MIN	ABSORPTION CALC TIME MIN
a			b		c	d	d	d	d	d	d	d	d
P7481 virgin	1	9	510	1	510	28	75	75	75	30μ	45	45	30
Post-vib.	2	9	510	1	510	28	75	75	75	30μ	45	45	30

			FEED CO₂		MMHG		FEED H₂O PK HT	FEED H₂O D.P. °F	MM HG	CYCLE # DATE	TEMPERATURE ROLL	TEMPERATURE FT	COMPOSITION ROLL	COMPOSITION FT
$(H_{CO_2} IN / F)$ $(P_{CO_2}CAL / H_{CO_2}CAL)$			e / h	f / f			l	j	k					
ATTENUATOR			a										III	73
CALIB	READ	F												
2	2	1												
2	1	2	1	(17.85) / (2)	3.64 / 10.5	3.09							VI	73
2	4	.5												
1	1	1												
1	2	.5	2	(17.85) / (2)	3.64 / 10.5	3.09								
4	2	2												
4	1	4												

ID →	a	1	2				a	1	2		
	CO_2	CO_2	CO_2	CO_2	CO_2		H_2O	H_2O	H_2O	H_2O	H_2O
MG											
(1) TOTAL AREA		[illegible]	5579					4592	4570		
(2) AREA BYPASS		[illegible]	4592					[illegible]	[illegible]		
(3) AREA ADS		[illegible]	7922					[illegible]	2962		
(4) TOTAL CALC		[illegible]	5574					4547	4535		
(3)/(4) x100 % REMOVAL EFF Σ		27.5	28.7					65.3	65.3		
	l										

NOTE: CALCULATIONS BELOW ASSUME TGAS 25 C

CO_2 CAPACITY RUN—ID	CAN	10^{-5}	2.367	P_{CO_2} IN MMHG	ΣCO_2 %	FLOW ML/MIN L	TIME MIN / VOL ML L	=	GM / L	VOLS ML L / 10 WT GM KG	=	% WT
		m						p			q	
a		10^{-5}	2.367						GM / L	1 / 10		% WT
P7481	1	10^{-5}	2.367	3.09	27.5	510	30 / 5	6.15	GM / L	5 / 1.82	1.69	% WT
Post-vib	2	10^{-5}	2.367	3.09	28.7	510	30 / 5	6.40	GM / L	5 / 1.87	1.71	% WT
		10^{-5}	2.367						GM / L	1 / 10		% WT
		10^{-5}	2.367						GM / L	1 / 10		% WT

H_2O CAPACITY		10^{-5}	0.962	P_{H_2O} IN MM HG	ΣH_2O %	FLOW ML/MIN L	TIME MIN / VOL ML L	=	GM / L	VOLS ML L / 10 WT GM KG	=	% WT
		n						p			q	
a		10^{-5}	0.962						GM / L	1 / 10		% WT
P7481	1	10^{-5}	0.962	9.3	65.3	510	30 / 5	19.2	GM / L	5 / 1.87	5.14	% WT
Post-vib	2	10^{-5}	0.962	9.3	65.3	510	30 / 5	19.2	GM / L	5 / 1.82	5.27	% WT
		10^{-5}	0.962						GM / L	1 / 10		% WT
		10^{-5}	0.962						GM / L	1 / 10		% WT

FIGURE 27

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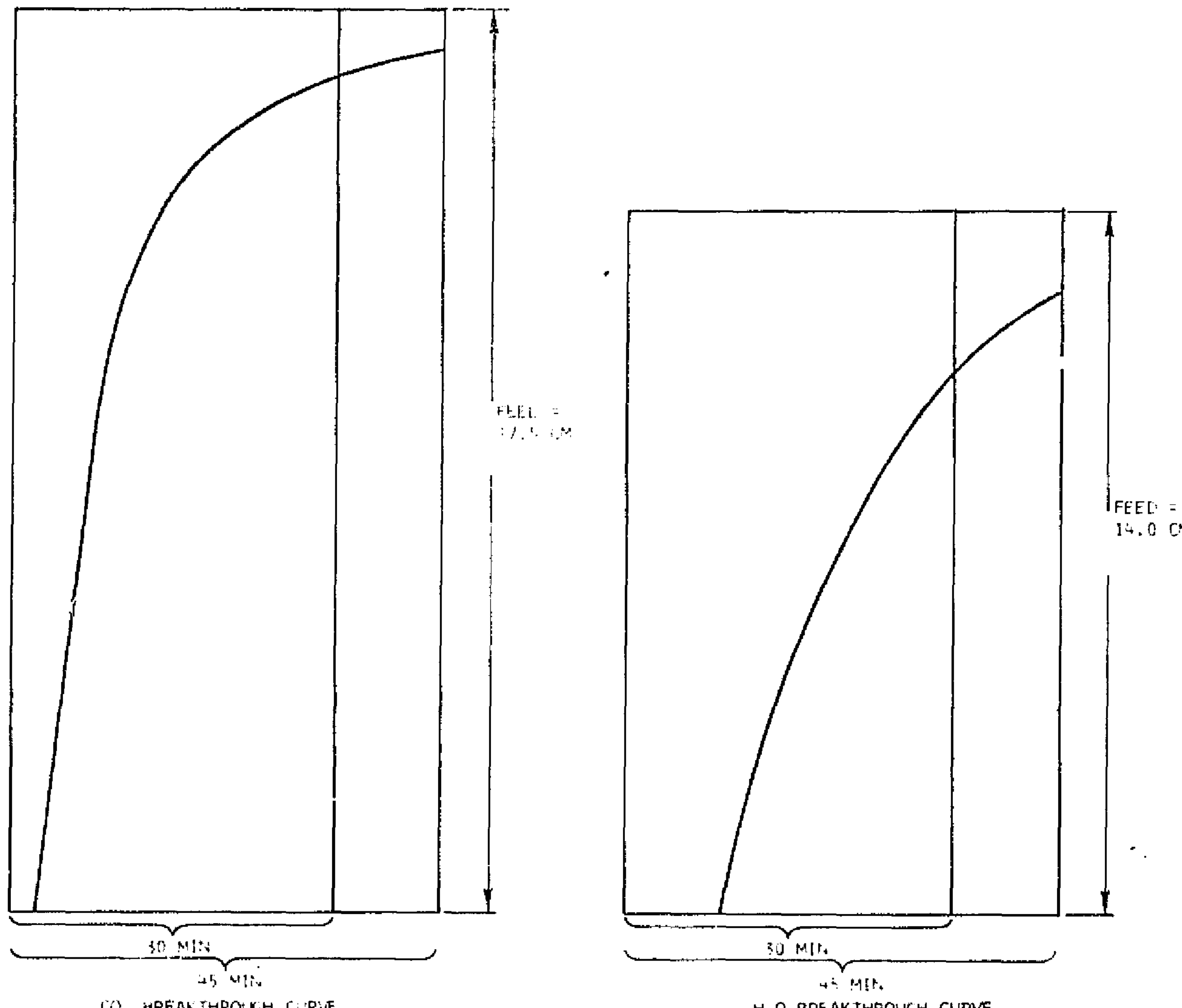
FIGURE 28



SMALL SCALE TESTS
BREAKTHROUGH CURVE TRACINGS FROM CHROMATOGRAM

XAD-7 is a polymeric acrylic ester (a relative of Plexiglas and other acrylic plastics) in the form of small spheres (typically 1/2 mm and smaller) which have many microscopic fissures, etc. making them very porous. They are white in color, and crush with moderate difficulty using the flat side of a knife. They swell to twice dry volume when wet with water or alcohol.

The coating is Dow PEI-18, a polyethylenimine (PEI) of the chemical form:

$$\left\{\begin{array}{ll} -CH_2-CH_2-NH_2 & (25\%) \\ -CH_2-CH_2-NH- & (50\%) \\ -CH_2-CH_2-N\langle & (25\%) \end{array}\right\}_n$$

It is thick and viscous (like cold molasses) with an average molecular weight of 1800 (hence PEI-18).

Evaluation

Prepared HS-C was evaluated in the small scale apparatus using a set cycle. These nominal conditions were:

Sample Size	5 ml
P_{CO_2}	3 mm Hg
Air Flow	500 ml/min
Air Pressure	28 in. Hg.
Air Dew Point	52°F
Bed Temperature	75°F
Desorb Pressure	50 microns or better at end of desorption
Cycle Times	45 minutes adsorption, 45 minutes desorption

The capacities were evaluated according to the procedures of the "Calculations" above. As originally reported in monthly reports, the small scale apparatus indicated capacities greater than those measured in the more accurate large scale tests. Subsequent to the large scale testing, the small scale rig was recalibrated and adjusted using standard gas mixture used for the large scale tests. Subsequent results appear to give quite good correlation at the design operating point.

MATERIAL VARIATIONS

Substrate

The XAD-7 shipped by Rohm & Haas was manufactured in batches, and these batches have differed in their adsorption rate and the particle size of the

finished HS-C. The maximum adsorption capacity, however, has been constant.

From a given batch of XAD-7, the largest particles will be 24 to 28 mesh. Smaller sizes (30-40 mesh) give a slight improvement (5%) in adsorption capacity while the larger substrate (24-28 mesh) has less pressure drop (Figure 2).

Coating Weight

With too little coating, all the available pore area is not coated with liquid. With too much coating, the excess liquid will tend to clog the pores of the substrate. There is, therefore, an optimum coating weight. Furthermore, this weight differes with substrate batch and particle size. Such capacity variations are shown in Figure 2.

Coating Composition

PEI-18 has been chosen as the HS-C coating of choice. Only limited tests with other related materials have been run, but it has been established that higher molecular weight polymers are not as effective.

Lower molecular weight polymers have a higher vapor pressure and have not been exhaustively explored. However, the simplest practical amine, TEPA Tetraethylenepentamine, showed improved capacities when compared to the optimized HS-C used in the large scale tests (Series I and II), especially at higher CO_2 partial pressures. Figure 1 shows the improvement in capacity; about 5% at P_{CO_2} = 5 mm Hg. Its vapor pressure is estimated to be 1 micron at room temperature; that of PEI-18 is unmeasurably low. Preliminary experiments indicate that the vapor pressure of TEPA can be lowered and the coating made insoluble by polymerizing the coating in place on the substrate. This procedure has been successfully applied to a PEI-18 coating rendering it insoluble and permitting steam desorption of the material in a CO_2 concentrator application. This approach was not used here because the polymerization does not enhance the performance of PEI-18 preparation when operating in the vacuum desorb mode, nor is such polymerization necessary to keep the coating in place on the substrate.

Selected HS-C Material

Run Series I and II (See Large Scale Tests, Appendix F)

Substrate Mesh Size	24-28 mesh
Coating Agent	PEI-18
Coating Weight	24.2%
Density	0.384 gm/cc

Run Series III (See Large Scale Tests, Appendix F)

Substrate Mesh Size	30-40 mesh
Coating Agent	PEI-18
Coating Weight	20.6%
Density	0.378 gm/cc

Reproducibility.- The techniques for preparing HS-C have been refined as a result of the requirement to manufacture a quantity of material during this program. Key improvements were made in washing, classifying, vacuum drying, and coating. The major contribution to uniformity resulting from the improved coating technique.

Present preparation techniques produce a material with performance variations of less than 5% overall when made to the same formulation. A table showing performance of the individual batches used for the 7-day test is shown in Appendix B.

HS-C LIFE TEST

Prior to the start of the present program, a 2000 hour life test of an early formulation of HS-C material was run in the small scale test apparatus.

The nominal 45 minute adsorb, 45 minute desorb cycle was run, with capacity calculated for the first 30 minutes of adsorb only. Table II shows the performance during the test, which included a parametric study.

At the beginning of the test the capacity of the material for CO_2 and water measured 1.95% and 5.45% by weight. After 2000 hours, the capacities were 2.00% and 6.12%, respectively. Since these capacities were taken from the small scale apparatus, the CO_2 weight could not be measured directly, so the capacity levels are, as usual, somewhat higher than a large scale test would show. Figure 3 shows the capacity variance throughout the life test.

SOLVENT TESTS

Objectives

Materials used in the spacecraft are likely to have been cleaned in organic solvents. It is important that sensitivity of the HS-C to such solvents be determined so that proper protection may be given the bed. The solvent tests were conducted to determine the effect of large quantities of gaseous solvent on bed performance.

Experimental Method

Incoming air to the small scale sorbent evaluator was passed over liquid solvent prior to entering the apparatus, tending to saturate the air to the vapor pressure of the solvent. In one case (Freon 113) the solvent vapor pressure was reduced by cooling to 50°F, otherwise room temperature solvent was used. The nominal adsorption/desorption conditions were run.[1]

Bed #1 was loaded with a preparation similar to those used for Run Series III of the large scale tests,[2] and bed #2 was loaded with material derived from an earlier batch of substrate used for Run Series I and II.

[1]See page 57
[2]See page 59

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CR-115568
SVHSER-6040

TABLE II

HSP 178 LA 1/66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

[illegible]

TABLE II [illegible] DATA SUMMARY

TYPE OF TEST: HS-C
TEST ENGINEER: LIFE TESTS
NAME OF RIG: Sample wt 1.89 gm
PROJECT & ENG. ORDER NO: Sample volume 5cc

SHEET 1 OF 1 DATE 7-14-71
TEST PLAN NO
MODEL NO
PART NO
SERIAL NO
OPERATORS

CODE	P_{CO_2} mm Hg	Dew Pt °F	Flow ml/min	Coolant temp[1] °F	Time for Desorb min	Time for Adsorb min	Time for Calcs min	CYCLE NO Start	CYCLE NO End	CYCLE NO Calc	Time into test[2] hrs		% Removal Efficiency CO_2	% Removal Efficiency H_2O	Cyclic Capacity gm/liter CO_2	Cyclic Capacity gm/liter H_2O	Cyclic Capacity wt % CO_2	Cyclic Capacity wt % H_2O
#5	3.02	50.5	940	75	45	45	30	—	—	5	7.5	NOM	19.3	40.5	7.36	20.6	1.95	5.45
A	3.49	50	940	75	45	45	30	1	64	31	46	NOM	17.3	44.9	8.05	22.9	2.13	6.05
B	3.[illegible]	50	940	75	45	45	30	65	70	68	104	NOM	17.6	44.0	7.26	22.5	1.93	5.95
C	3.41	49.5	503	75	45	45	30	71	77	74	113		36.8	68.8	8.95	18.8	2.37	4.95
J	1.90	49.5	940	75	45	45	30	78	82	81	123		30.6	46.3	7.75	23.5	2.05	6.23
D	5.19	49.[illegible]	940	75	45	45	30	83	85	85	127		12.5	4[illegible].0	8.65	21.8	2.29	5.75
E	3.30	41	940	85	45	45	30	86	93	88	13[illegible]		20.8	37.4	9.13	19.0	2.42	5.02
F	3.11	49.	940	65	45	45	30	94	96	96	141		18.0	46.6	7.46	23.1	1.98	6.10
G	2.18	62.	140	75	45	45	30	97	103	98	144		20.5	44.5	8.13	34.9	2.15	9.25
H	2.24	42.	940	75	45	45	30	104	112	107	158		14.4	42.7	5.45	15.1	1.44	3.99
K	2.4	51	685	75	45	45	30	128	129	129	192		32.2	52.5	8.70	20.0	2.30	5.30
L	2.71	[illegible]	29[illegible]	[illegible]	45	[illegible]	30	13[illegible]	145	144	[illegible]		63.0	87.5	7.06	13.9	1.87	3.66
M	2.81	50.5	566	75	45	[illegible]	[illegible]	146	[illegible]	[illegible]	222		36.5	65.5	8.30	21.4	2.20	5.66
M′	0.512	50 NOM	90[illegible]	75	45	45	[illegible]	150	151	151	242		52.2	(3)	4.48	(3)	1.19	(3)
N	0.50	[illegible]	11[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	246		25.1	(3)	3.51	(3)	0.92	(3)
O	3.16	50	453	75	30	30	30	154	175	175	267		35.6	71.5	7.24	17.5	1.91	4.64
OO	3.26	51	453	75	45	45	30	195	196	196	268		42.0	63.0	8.79	15.9	2.29	4.20
#292	2.81	51	940	75	45	45	30	—	—	292	532	NOM	19.7	40.6	7.38	21.2	1.95	5.62
	3.51	50	940	75	45	45	30	—	—	741	1200	NOM	16.0	47.7	7.50	23.6	1.99	6.25
	2.84	50	940	75	45	45	30	—	—	1315	2030	NOM	19.9	43.1	7.54	23.2	2.00	6.12

REMARKS:
P_{ADSORB} = 28 in. Hg P_{DESORB} = 50 μ Hg
T_{ADSORB} = 80°F

1 ADSORB AND DESORB
2 TIME ON LINE
3 H_2O OFF SCALE DATA NOT AVAILABLE

79286

HS-C LIFE TESTS

After cyclic equilibrium was reached, initial capacities were calculated, and then the beds were fed with solvent-contaminated air for 10 cycles and another capacity was taken. Then the solvent contamination was removed and the beds were cycled for about 6 recovery cycles and the capacity again measured.

Results

Resultant data are given in Table III. Results are more erratic than usual with this apparatus because the solvents affected the chromatographic columns, confusing the analyses by shifting the baseline. Sometimes the solvent caused a slight (±10% for CO_2, ±20% for H_2O) capacity increase and sometimes a decrease. There was little correspondence between beds 1 and 2 even though both saw the same feed composition. Apparent water capacity was most severely affected, probably because of the analysis problem, swinging ±20% from the initial capacity, while CO_2 capacity varied ±10%.

Conclusions

After exposure to all three solvents the beds recovered at least 90% of their original performance in both CO_2 and H_2O capacity. At most, the effect was 10% performance loss, but even this figure is believed pessimistic because of the interference with chromatographic analysis preduced by the solvents.

STRUCTURAL TESTS

When HS-C serves aboard a space vehicle, it must be physically capable of withstanding the launch environment. HS-C structural soundness tests were therefore derived from the tests used for the LM LiOH canister, and these tests were run using HS-C in a LM canister as a part of Hamilton Standard's general CO_2 and humidity control program (Independent Research and Development).

The complete test plan and results are given as Appendix A. In summary, four types of test were run before and after shaking the canister and no degradation was noted. The resistance to dusting was evaluated directly by microscopic examination, counting fractured HS-C particles, and indirectly by measuring canister pressure drop and apparent density. The adsorptive capacity of the material before and after shaking was also measured.

The results of these tests were all negative. Summary quantitive figures abstracted from Appendix A are given in Table I.

Hamilton Standard — WINDSOR LOCKS, CONNECTICUT • U.S.A.

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LOG OF TEST
ENGINEERING LABORATORIES

RIG NO
TYPE OF TEST: SOLVENT TESTS
W.P.I. NO.
PLAN OF TEST NO
SERIAL NO
PART NO
DATE
ENGINEER
OPERATORS

SOLVENT	Vol% in feed	Bed No.	Capacity of	Initial	Capacity in wt.% with solvent	after recovery
FREON 113	0.03	1	CO_2	1.57	1.65	1.47
			H_2O	4.09	4.43	4.21
		2	CO_2	1.59	1.57	1.51
			H_2O	4.36	4.27	3.89
TETRACHLORO-ETHYLENE	0.04	1	CO_2	1.47	1.49	1.65
			H_2O	4.21	3.49	4.31
		2	CO_2	1.51	1.46	1.50
			H_2O	3.89	3.37	4.30
TRICHLORO-ETHANE	0.04	1	CO_2	1.65	1.49	1.54
			H_2O	4.31	3.97	3.75
		2	CO_2	1.50	1.63	1.42
			H_2O	4.30	4.10	4.00

All tests:
- Adsorption time: 45 minutes
- Calculated for: 30 minutes
- Desorption time: 45 minutes
- Pressure: 28 in Hg
- Air inlet temp: 68° F
- Canister temp: 75°F
- Desorption press: 40μ (min.)
- P_{CO_2} (inlet): 3 mm Hg
- Dew point (inlet): 52°F
- Air flowrate: 500 ml/min.
- Sample size: 5ml (~2gm)

REMARKS: BED 1 Preparation P-3930 (Made from substrate used for Run Series III)
BED 2 Preparation P-4536 Made from substrate used for Run Series I & II)

PAGE NO
REPORT NO

TABLE III

RESULTS OF SOLVENT TESTS

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FLAMMABILITY TESTS

HS-C is a nonmetallic material and therefore falls under the jurisdiction of D-NA-0002 (Procedures and Requirements for Flammability and Offgassing Evaluation of Manned Spacecraft Nonmetallic Materials).

As part of Hamilton Standard's general CO_2 and Humidity Control Program (Independent Research and Development) HS-C material was subjected to flammability tests, using the projected shuttle atmosphere of standard air.

Results

Test No.	Description	Results
2	Downward Propogation Rate	Self extinguishing after 3/8" burn.
3	Flash and Fire Point	No visible flash below 400°F, no combustion below 450°F.
8	Materials in Vented Containers	No ignition when subject to the most severe ignition source.

Discussion

Test No. 2 and 3 are standard tests and were conducted following the procedure from D-NA-0002.

The flammability test for materials in vented containers is Test No. 8, the pertinent portions of which are quoted below:

Sample Preparation:

> The container shall be the same size, geometry and material as the flight container.
>
> The equipment to be tested shall be the same, with regard to the nonmetallics, as the flight equipment. Electronic parts and similar expensive metallic or ceramic entities may be simulated.
>
> The equipment shall be packaged and positioned in the container in the same manner as in the flight article.

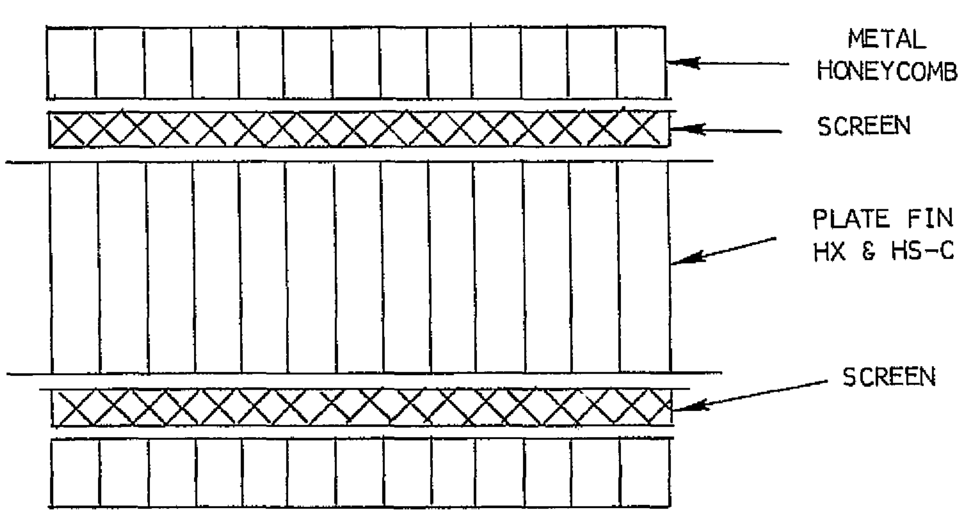
Ignition Source:

External Ignition - Any container without an internal ignition source.

Ignition Source - a flame source representative of the worst possible S/C fire shall be placed outside the container opposite the most combustible material in the test configuration. Sufficient energy shall be supplied to ignite the configuration or assure that it will not ignite in actual service. The contractor shall furnish analyses to support the selection of ignition sources.

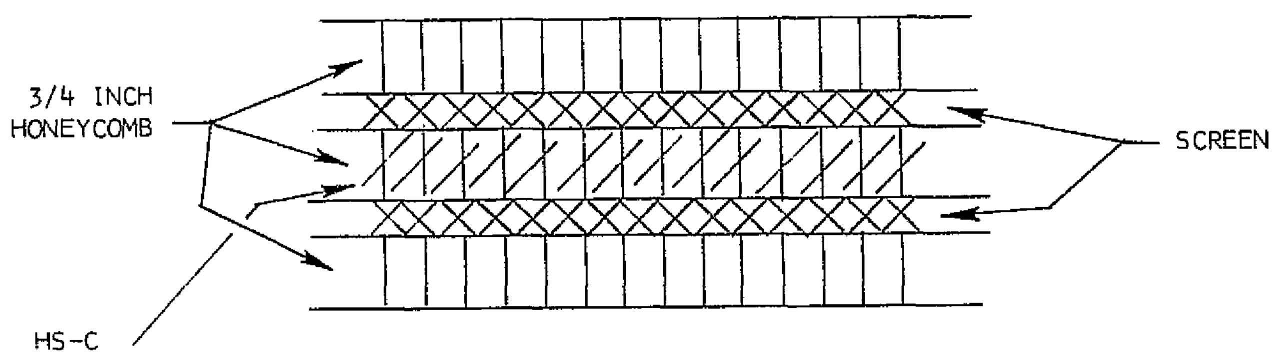
The described test was performed on a representative HS-C canister configuration, which successfully passed. The details of this test are described below.

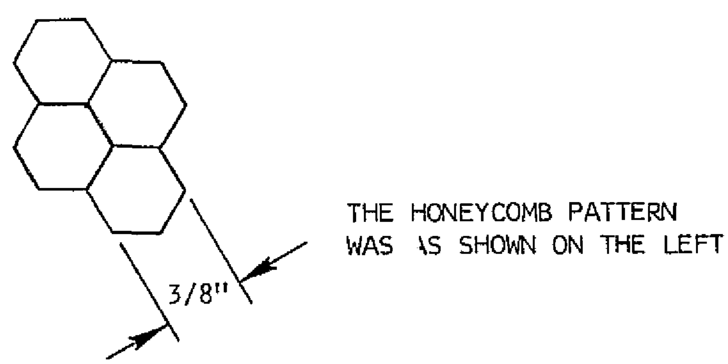
The proposed HS-C canister design is one which prevents both ignition and propagation. It consists of a plate fin type heat exchanger with relatively small passages, which contain the HS-C.



Screens are placed over both faces at the heat exchanger, and a metallic honeycomb is used to retain the screen. In this configuration, the screen acts as a flame barrier and the honeycomb prevents propagation. This is the configuration used for performance testing.

A representative model of the configuration described above was used for flammability testing. It consisted of three layers of honeycomb, the middle layer representing the heat exchanger.





With the passages in a vertical position, a gas burner flame was held under the test unit. After a period of about 15 seconds, the screen started to glow red and the honeycomb (aluminum) began to melt locally.

The HS-C material began to give off a white smoke. The flame was then removed. Within one minute after flame removal, the smoke evolution ceased. At no time was there a visible flame from the HS-C.

The unit was disassembled and the HS-C examined. Approximately one layer of HS-C (0.02") was discolored a light shade of brown.

TOXICANT TEST

It is necessary, of course, that the HS-C effluent gas be safely breathable in normal operation and in failure modes. A sample of HS-C effluent gas was taken at the close of the large scale tests (Run Series I, cycle 150, p F-13) and analyzed. Similar gas samples were taken from HS-C used for Run Series I and II after heating to 180°F with a volume of atmospheric air simulating the spacecraft cabin according to a preliminary specification (see Hamilton Standard's Plan of Test, Appendix C). Later samples from Run Series III were tested to Specification MSC-PA-D-67-13, Addendum 1, 1A, 2, 2A, which calls for heating for 72 hours at 155° ±5°F followed by a day's cooling prior to analysis. Analysis was made only for ammonia. Detailed results of the toxicant tests are given in Appendix C.

Discussion

The toxicant analysis in the air volume simulating the shuttle cabin levels after 1, 6, and 24 hours shows no clear trend of contaminant increase except for brominated hydrocarbons. Brominated hydrocarbons, ammonia and toluene are the only components which reach undesirable toxicant concentrations.

150 to 300 μ gms NH_3 per gram of HS-C were observed in the toxicant tests to specification MSC-PA-D-67-13, confirming the ammonia evolution observed in the earlier toxicant tests.

Bromine

The source of the unsaturated brominated hydrocarbons cannot be HS-C, for bromine is not used in the manufacture of either substrate or coating agent. It is presumed that the contamination was caused by the heavy manometer fluid ABr_4 which was used in test rig 88. The main constituent of this material[1] is heavily brominated and boils at 151°C, but it is not reported in the gas analyses. The materials reported are the impurities to be expected during the manufacture of ABr_4 from acetylene and bromine.

[1] tetrabromoethane or commonly acetylene tetrabromide (ABr_4)

Ammonia

Ammonia almost certainly arises from the HS-C coating agent, which is an amine. Subsequent investigation has shown that the batch of coating agent used for Series I tests was contaminated during manufacture with ammonia (to about 0.2%), was manufactured in 1968. A newer (1970) batch of coating agent was obtained and used to make the HS-C for Run Series III, but tests conducted with this material also produced high ammonia levels.

Toluene

Toluene is a known contaminant in the substrate. Most of it is washed from the bed during the alcohol wash. Remaining traces detected by the toxicant test probably were vaporized from the depths of the porous substrate. This material is expected to be removed if the HS-C is heated (without air) to 180°F for 24 hours. The HS-C prepared for Run Series I was heated to 135°F for 24 hours, and that for Run Series III for 48 hours.

Conclusion

HS-C evolves 150-300 μgms of ammonia per gram of HS-C when heated in air to 155°F and cooled for 24 hours. High levels of ammonia were also found when the HS-C was not cooled prior to analysis.

Recommendations

Future HS-C preparations should be fully desorbed during preparation at more severe conditions than those expected in flight to remove all contaminants prior to contaminant evaluation. Means for reducing or eliminating ammonia evolution should be investigated.

COMPUTER PROGRAM DESCRIPTION

INTRODUCTION

The HS-C computer program predicts water and CO_2 adsorption and desorption rates along the length of an HS-C bed, calculating effluent gas composition and residual bed loadings as a function of time. Single modes or a succession of adsorption/desorption cycles can be calculated.

The bed can be cooled/heated during adsorption/desorption by cross-flow heat exchange with a cooling/heating fluid. An option for infinite conductance and flow allows prediction of the performance of an isothermal bed. This may be used as a reference point to evaluate system performance.

Desorption can be by gas purge with a pure inert gas, or with a fixed vacuum. Concentration and (for vacuum desorption) pressure gradients are calculated along the length of the bed.

DESCRIPTION AND MATHEMATICAL MODEL

The following mathematical description of the adsorption and desorption of both H_2O and CO_2 on HS-C illustrates an application of the fundamental principles of surface chemistry and reaction kinetics to an adsorption phenomena.

Adsorption and Desorption

The rate of mass transport and sorption of gases flowing through a packed sorbent bed depends on the following adsorption considerations (desorption is assumed to be a reversal of the adsorption process):

1. Diffusion of the sorbates to the surface of the sorbent particles or beads (i.e., diffusion through the boundary layer).

2. Diffusion through the porous beads to the surface sites.

3. Rate of chemisorption at the surface site.

Experimental studies have shown that step 3, chemisorption, is the rate controlling mechanism. The chemisorption process equations in the mathematical model include the simultaneous adsorption of H_2O and CO_2 in the material as well as a CO_2 enhancement reaction with adsorbed H_2O.

The chemisorption reaction mechanism of HS-C is as follows:

There are three kinds of sites, X, Y and Z. X sites react only with CO_2; Y and Z sites only with H_2O, thus, as have been previously introduced:

$$X + CO_2(g) \underset{k_{XR}}{\overset{k_X}{\rightleftharpoons}} X \cdot CO_2 \qquad (1)$$

$$Y + H_2O(g) \underset{k_{YR}}{\overset{k_Y}{\rightleftharpoons}} Y \cdot H_2O \qquad (2)$$

$$Z + H_2O(g) \underset{k_{ZR}}{\overset{k_Z}{\rightleftharpoons}} Z \cdot H_2O \qquad (3)$$

Production of $Y \cdot H_2O$ gives rise to another reaction:

$$Y \cdot H_2O + CO_2(g) \underset{k_{Y \cdot H_2OR}}{\overset{k_{Y \cdot H_2O}}{\rightleftharpoons}} Y \cdot H_2O \cdot CO_2 \qquad (4)$$

For reactions 1, 2, 3, and 4, the forward and reverse reaction rate coefficients (k) have been noted. This mechanism explains the following experimental observations:

1. High capacity for CO_2 removal in the presence and absence of $H_2O(g)$ - demonstrated by reaction #1.
2. High capacity of H_2O removal in the presence and absence of $CO_2(g)$ - demonstrated by reactions #1 and #3.
3. Enhancement of $CO_2(g)$ capacity by the presence of large amounts of $H_2O(g)$ - demonstrated by reaction #4.

Mathmatical Formulation

The equations for the adsorption/desorption mechanism which have been impelmented in the digital computer simulation are:

Rate Equations

$$\frac{-dX}{dt} = (K_X)(P_{CO_2})(X) - (K_{XT})(X.CO_2)$$

$$\frac{-dy}{dt} = (K_y)(P_{H_2O})(Y) - (K_{yT})(Y.H_2O)$$

Rate Equations

$$\frac{-dz}{dt} = (K_z)(P_{H_2O})(Z) - (K_{zr})(Z.H_2O)$$

$$\frac{-d(Y.H_2O)}{dt} = (K_{y.H_2O})(P_{CO_2})(Y.H_2O) - K_{y.H_2OR}(Y.H_2O.CO_2)$$

$$\frac{dM_{H_2O})\ out}{dt} = +\frac{dM_{H_2O}\ in}{dt} - \frac{dM_{H_2O})\ ad}{dt}$$

where: $$\frac{dM_{H_2O}}{dt} = \left(\frac{dy}{dt} + \frac{dz}{dt}\right) W_{bed}$$

$$\frac{dM_{CO_2})\ out}{dt} = \frac{-dM_{CO_2})}{dt}\ in\ \frac{-dM_{CO_2})\ ad}{dt}$$

where: $$\frac{dM_{CO_2})\ ad}{dt} = \left(\frac{dx}{dt} + \frac{d(Y.H_2O)}{dt}\right) W_{bed}$$

Perfect Gas Law $PV = MRT$

Arrhenius' Law $K = K_o\ ^{-E/RT}$ expresses dependency of rate constants on temperature

where:

P_{CO_2} = Partial Pressure of CO_2, mm Hg

P_{H_2O} = Partial Pressure of H_2O, mm Hg

(X) = Site concentrations available for CO_2, $\frac{\text{lb-mole}}{\text{lb}_{bed}}$

$(X.CO_2)$ = Site concentrations not available for CO_2, $\frac{\text{lb-mole}}{\text{lb}_{bed}}$

(Y) = Site concentrations available for H_2O, $\frac{\text{lb-mole}}{\text{lb}_{bed}}$

$(Y.H_2O)$ = Site concentrations not available for H_2O, but available for CO_2, $\frac{\text{lb-mole}}{\text{lb}_{bed}}$

$(Y.H_2O.CO_2)$ = Site concentrations not available for CO_2, $\frac{\text{lb-mole}}{\text{lb}_{bed}}$

(Z) = Site concentrations available for H_2O, $\frac{\text{lb-mole}}{\text{lb}_{bed}}$

$(Z.H_2O)$ = Site concentrations not available for H_2O, $\frac{\text{lb-mole}}{\text{lb}_{bed}}$

K_x = Forward rate coefficient for CO_2 on X sites, $\frac{1}{\text{min-mm Hg}}$

K_{xr} = Reverse rate coefficient for CO_2 on X sites, $\frac{1}{\text{min}}$

K_y = Forward rate coefficient for H_2O on y sites, $\frac{1}{\text{min-mm Hg}}$

K_{yr} = Reverse rate coefficient for H_2O on y sites, $\frac{1}{\text{min}}$

K_z = Forward rate coefficient for H_2O on z sites, $\frac{1}{\text{min-mm Hg}}$

K_{zr} = Reverse rate coefficient for H_2O on z sites, $\frac{1}{\text{min}}$

$K_{y.H_2O}$ = Forward rate coefficient for CO_2 on $y._{H_2O}$ sites, $\frac{1}{\text{min-mm Hg}}$

$K_{y.H_2OR}$ = Reverse rate coefficient for CO_2 on $y._{H_2O}$ sites, $\frac{1}{\text{min}}$

$M_{H_2O})_{in}$	=	moles of H_2O into node
$M_{CO_2})_{in}$	=	moles of CO_2 into node
$M_{H_2O})_o$	=	moles of H_2O out of node
$M_{CO_2})_o$	=	moles of CO_2 out of node
$M_{H_2O})_{ad}$	=	moles of H_2O adsorbed
$M_{CO_2})_{ad}$	=	moles of CO_2 adsorbed
R	=	gas constant - 555 $\frac{ft^3\text{-mm Hg}}{\text{lb-mole-°R}}$
T	=	carrier gas temperature, °R
K_o	=	rate coefficient independent of temperature
W_{bed}	=	weight of bed material, lb.

Vacuum Desorption Pressure Distribution

Calculation of nodal pressures during vacuum desorption requires consideration of pressure gradients through the bed and the void volume of the bed.

The pressure at each end of the bed is specified either as an input or can be calculated within the computer program to allow for either single or double end vacuum desorption.

The mathematical model uses the polytropic process equation along with the equation of state to relate time rate of pressure change with mass flow rate of constituents through the bed

$$\frac{P}{\rho^{\gamma}} = \text{const}$$

$$PV = WRT$$

The equation relating rate of pressure to mass flow rate becomes

$$\dot{P} = \frac{\gamma RT}{V} \dot{W} \qquad \begin{array}{l} \gamma = 1.0 \text{ isothermal process} \\ \gamma = 1.4 \text{ adiabatic process} \end{array}$$

It is assumed in the model that the flow through the bed is laminar and can be defined by

$$W = \frac{A\ D^2\ E^3\ P_{tot}}{298{,}000 \quad L\ (1-E)^2\ T_G} (P_{Tin} - P_{Tout})$$

where: $\dot{W}$ - lb moles/min

P_{TOT} - average total pressure (mmHg)

P_{Tin} - total inlet pressure (mmHg)

P_{Tout} - total outlet pressure (mmHg)

T_G - process gas temperature (°R)

μ - viscosity (lb-sec/in^2)

D - bead diameter (inches)

L - bed length (inches)

A - bed cross sectional area (in^2)

E - bed void fraction

Mathematical Formulation

The equations for the vacuum desorption pressure calculation which have been implemented in the digital computer simulation are:

outlet flow from each node

$$D_{MO_i} = D_W P_{T_{avg}} (P_{T_i} - P_{T_{i+1}})$$

where: $P_{T_{avg}} = (P_{T_i} + P_{T_{i+1}})/2$

$$D_W = \frac{A\ D^2\ E^3}{298{,}000 \quad L\ (1-E)^2\ T_G}$$

Inflow to 1st node

$$D_{MI} = D_W P_{T\,avg} (P_{in} - P_{T_1})$$

$$P_{Tavg} = (P_{in} + P_{T1})/2$$

Mole flow of constituents

$$D_{MH_1} = \left(\frac{P_{H_2O_1}}{P_{T_1}}\right) D_{MI_1} \qquad D_{MC_1} = D_{MT_1} - D_{MH_1}$$

$$D_{MC_i} = D_{MCO_{i-1}} \qquad D_{HC_i} = D_{HCO_{i-1}} \ (i = 2 \ldots n)$$

$$D_{MHO_i} = \left(\frac{P_{H_2O_k}}{P_{T_k}}\right) D_{MO_i} \qquad \begin{array}{l} k = i \text{ for positive } D_{MO_i} \\ k = i + 1 \text{ or negative } D_{MO_i} \end{array}$$

$$D_{MCO_i} = D_{MO_i} - D_{MHO_i}$$

Average nodal partial pressures

$$P = \int_0^t \dot{W} \frac{RT}{V}$$

where: V - node void volume, (ft^3)

T - node process gas temperature, (°R)

R - 555 ft^3-mmHg/°R lb mole

$\dot{W}$ - net mole flow rate into or out of node void volume

γ - ratio of specific heats (assumed $\gamma = 1.$)

D_{MO_i} - total mole flow rate out of node (lb mole/min)

$P_{T_{avg}}$ - average nodal total pressure (mmHg)

P_{T_i} - node inlet total pressure (mmHg)

$P_{T_{i+1}}$ - node outlet total pressure (mmHg)

D_{MI} - total mole flow rate into 1st node (lb mole/min)

D_{MH_i} - node inlet H_2O mole flow rate (lb mole/min)

D_{MC_i} - node inlet CO_2 mole flow rate (lb mole/min)

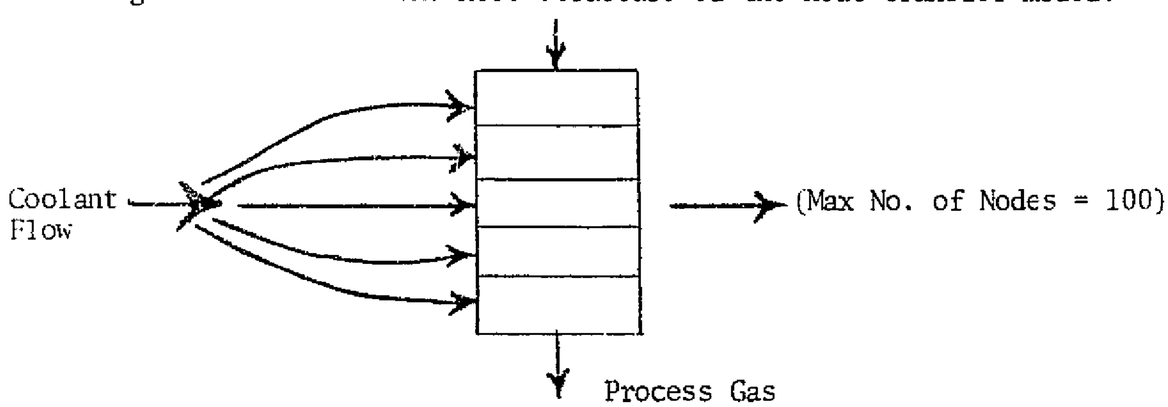
D_{MHO_i} - node outlet H_2O mole flow rate (lb mole/min)

D_{MCO_i} - node outlet CO_2 mole flow rate (lb mole/min)

Heat Transfer

To predict performance of a non isothermal bed a crossflow air-air heat exchanger was modeled. The heat transfer analysis is taken from "Computer Analysis Techniques for Spacecraft Adsorption Beds" by R. L. Blakely and B. N. Taylor, McDonnell Douglas, March 17, 1969.

The figure below shows the node structure of the heat transfer model.



The number of nodes in the process gas flow direction is equal to the number of nodes represented in the chemisorption kinetic model. Heat exchanger core temperature, bed temperature and the process gas temperature are calculated at each node. Average coolant gas outlet temperature is also calculated. Heat conduction in the axial direction of the process gas is included, and a log mean temperature difference is assumed between the heat exchanger temperature and coolant gas temperature, as well as between bed temperature and process gas temperature.

Mathematical Formulation.-

Bed Node Heat Transfer

$$\left(\frac{T_{B_X} - T_{B_X\,past}}{t}\right) M_B C_{PB} = \left(\dot{W}_{AIR_X} C_P + \dot{W}_{H_2O_X} C_{P_{H_2O}} + \dot{W}_{CO_{2_X}} C_{P_{CO_2}}\right)\left(1 - e^{-A}\right)$$

$$\left(T_{G_{X_{in}}} - T_{B_X}\right)$$

METHOD OF SOLUTION

The transient processes involved in the adsorption and desorption modes are carried out using a finite difference technique employing multiple nodes. For each node the rates of adsorption of CO_2 and H_2O are calculated based on past values of loading and partial pressure, and the heat transfer rates are calculated based on past values of temperatures, and the constituent flow rates through the bed. Simple rectangular integration is employed to integrate the rates to obtain the loadings of each constituent, temperatures of the bed and process gas, and nodal pressures during vacuum desorption.

$$+ U_{BHX}A_{BHX}\,(T_{HX_X} - T_{B_X}) + \sum QR_X + \frac{K_B A_B}{\Delta X}\,(T_{B_{X-1}}\ \ T_{B_X})$$

$$+ \frac{K_B A_B}{\Delta X}\,(T_{B_{X+1}} - T_{B_X})$$

$$T_{GOUT_X} = T_{B_X} + (T_{Gin_X} - T_{B_X})\,e^{-A}$$

where:

$$U_{B_{HX}} = \frac{1}{\frac{1}{h_B} + \frac{1}{h_{HX}}}$$

$$h_B = f\,(\dot{W}_{REAC}) = f\,(\dot{W}_{AIR} + \dot{W}_{H_2O} + \dot{W}_{CO_2})$$

$$h_{HX} = f\,(\dot{W}_C)$$

$$A = \frac{h_B\ A_{BHX}}{W_{REAC}\ C_P}$$

Heat exchanger node heat transfer

$$\frac{T_{HX_X} - T_{HX_{Xpast}}}{\Delta t} M_{HX}C_P = \dot{W}_C C_{P_C}\,(1 - e^{-B})(T_{C_{in}} - T_{HX_X})$$

$$+ U_{BHX}A_{BHX}(T_{B_X} - T_{HX_X}) + U_{AMB}A_{AMB}\,(T_{AMB} - T_{HXX})$$

$$+ \frac{K_{HX}A_{HX}}{(X-1)-X}\,(T_{HX_{X-1}} - T_{HX_X}) + \frac{K_{HX}A_{HX}}{X - (X+1)}\,(T_{HX_{X+1}} - T_{HX_X})$$

$$T_{COUT_X} = T_{HX_X} + (T_{C_{in}} - T_{HX_X})\ e^{-B}$$

where: $$B = \frac{h_C A_{CHX}}{\dot{W}_C C_{PC}}$$

$$h_C = F\ (\dot{W}_C)$$

PROGRAM CAPABILITIES

The program predicts either the isothermal or nonisothermal performance of a single adsorption period (used for analyzing a breakthrough curve), a single vacuum or inert gas purge desorption period (knowing initial bed loadings at the beginning of the desorption run), and cyclic operation with either vacuum desorption or gas purge desorption. In addition the program predicts CO_2 adsorption in a dry atmosphere and H_2O adsorption in a CO_2 free atmosphere.

Program Options

- Isothermal Operation
  set ISOT (8) = 0.
  set TCIN (35) = Isothermal Bed Temperature

- Nonisothermal Operation
  set ISOT (8) = 1.
  set TCIN (35) = Coolant Inlet Temperature

- Single Adsorption Period
  set IND (6) = 0.
  ADSORB (39) = TMAX (2)
  PIH2O (15) = inlet H_2O partial pressure
  PICO2 (16) = inlet CO_2 partial pressure

- Single Vacuum Desorption Period
  set IND (6) = 1.
  DESORB (40) = TMAX (2)
  IDES (7) = 0.
  PIH2O (15) = inlet H_2O partial pressure at end of adsorption
  PICO2 (16) = inlet CO_2 partial pressure at end of adsorption
  PAIR (33) = initial total process gas pressure
  Q (34) = process flow rate during adsorption needed to initialize the heat exchanger
  XJ (9) = number of passes through vacuum pressure calculation each system pass

- Single Gas Purge Desorption Period
  set IND (6) = 1.
  DESORB (40) = TMAX (2)
  IDES (7) = 1.
  PIH2O (15) = inlet H_2O partial pressure at end of adsorption
  PICO2 (16) = inlet CO_2 partial pressure at end of adsorption
  PAIR (33) = initial total process gas pressure
  Q (34) = purge gas flow rate

- Cyclic Operation
  set IND (6) = 0.
  ADSORB (39) = desired adsorb period
  DESORB (40) = desired desorb period
  IDES (7) = 0 for vacuum desorption
  1 for inert gas purge desorption

PROGRAM RESTRICTIONS

- Only allows an inert gas purge (cannot use for gas purge with some P_{H_2O} or P_{CO_2} in the gas.
- Does not allow for desorption at pressures above the partial pressure of H_2O and CO_2.
- The pressures at each end of the bed during vacuum desorption must be specified as program inputs (does not include a simulation for a vacuum system).
- Inlet process gas temperature and inlet coolant temperature are constant (specified as program inputs) and can not be varied during the transient.

INPUT/OUTPUT PARAMETERS

Input/output parameters for the computer program are listed in Appendix D.

PROGRAM FLOW CHARTS

Program flow charts for the computer program are listed in Appendix D.

PROGRAM SYMBOL DEFINITIONS

Program symbol definitions for the computer program are listed in Appendix D.

PROGRAM SOURCE LISTINGS

Program source listings and a sample case output for the computer program are given in Appendix D.

SAMPLE CASE

A sample case has been processed for cycle 16 of Run Series III (large scale tests) and included at the end of the computer output (Appendix D).

The CO_2 and water capacities predicted by the program well represent the observed data of cycle 16. This agreement was achieved by using kinetic constants obtained from work with an earlier HS-C material and modifying them to fit the data of cycle 16. Proper constants should be obtained for the material to be used on the next contract phase before the computer program is used to predict performance very far from test conditions.

LABORATORY CONCEPT DEVELOPMENT

The two HS-C materials selected for test in "Material Variations" were tested in the laboratory in large (5 and 10 lb) and small (2 gm) scale tests.

The larger mesh size material was exhaustively tested in small scale tests, with twelve tests exploring performance variations due to changes in CO_2 feed concentration, inlet dew point, adsorption/desorption temperature, inlet flow rate, and cycle time. The smaller mesh material was run at nominal conditions only during the corresponding small scale tests.

For the large scale tests, 10 pounds of the larger mesh material were extensively, with fifteen parametric tests totaling 219 continuous hours (Run Series I) exploring the performance changes resulting from changes in inlet air temperature, inlet dew point, bed adsorb/desorb temperature, inlet CO_2 concentration, inlet air flow, cycle time, and desorption pressure.

To explore the effect of bed thickness, the bed was repacked with 5 pounds of the larger mesh size material and 22 additional hours of test accumulated (Run Series II).

Using the smaller mesh size material, a series of seven tests explored variations in cycle time, inlet dew point, inlet air flow, and inlet CO_2 concentration. 228 hours of continuous test were accumulated (Run Series III).

SMALL SCALE DEVELOPMENT TESTS

The small scale apparatus previously described was used for the parametric tests of the HS-C material used in the Series I tests.

Test Objectives

The small scale test objectives were:

- To obtain parametric data prediction of large scale tests so as to minimize expensive large scale running time.
- To obtain parametric data over a wider range of variables than convenient with the large scale equipment.

Test Accuracy

Data taken with with the small scale apparatus showed about 20% more capacity than was later confirmed with the large scale tests. This discrepancy was reduced by recalibration of the small scale apparatus with calibration gas used for the large scale tests. The trends in the parametric tests remain valid for they were confirmed in the large scale tests. The precision of the small scale tests is estimated as ±10% or better. For accurate comparisons necessary during material development phases, the two beds are used in a comparative mode. In this manner comparative results are obtained that are precise to within ±5%.

Differences Between Large and Small Scale Tests

Except for test canister configuration and sample size, there were no important differences between conditions set for "nominal" small and large scale runs. Inlet gas flow rate was ratioed upward with sample size. Adsorption cycle time was cut to 30 minutes in the large scale tests because at this point CO_2 adsorption was complete.

Test Canisters

The canister for the small scale apparatus was a 1/2 inch stainless steel tube (0.035 in. wall) with screens on each end. The 5 ml test sample (about 2 grams) was 2 in. deep, and desorption was single end only. The 5 or 10 pound charge of HS-C in the large scale canister was 1-1/2 or 3 in. deep, normally desorbed from both ends. The flow passages were 14 in. x 0.15 in. The concentration of CO_2 leaving the bed at the start of the adsorb cycle was zero for the small scale tests, but about 1/3 the feed composition in the large scale tests. This was interpreted as indicative of a large (33%) by-pass flow around the HS-C in the large scale canister, probably resulting from the numerous small (0.15 in.) air flow passages of the large scale canister.

Parametric Data Description

Parametric data is presented on calculation sheets (Table IV). and graphs (Figures 4 through 8). There are two points each for the CO_2 and H_2O adsorption of a given run, one calculated for 30 minutes adsorption time and one for the full 45 minutes.

SORBENT EVALUATOR CALCULATION SHEET

USE FLOW IN LITERS/MIN OR ML/MIN; WT IN KG OR GM; VOL IN LITERS OR ML

SAMPLE IDENTIFICATION		RAW FLOW RDG	CAL FLOW	FACTOR (1.3 FOR CFM, 472 FOR CFH)	FLOW LITERS/MIN (ML/MIN)	PRESS. IN HG	ADSORPTION AIR INLET T F	ADSORPTION WATER TEMP F	DESORPTION WATER TEMP F	DESORPTION PRESS. IN HG OR μ	DESORPTION TIME MIN	ADSORPTION TIME MIN	ADSORPTION CALC TIME MIN
P7481 Bed 2 Nom.	1	9	510	1	510	28	75	75	75	30μ	45	45	30/45
Bed 1 Hi flow 1000	2	17	1000	1	1000	↓	↓	↓	↓	↓	↓	↓	↓
Bed 1 Hi CO_2 5mm	3	9	510	1	510	↓	↓	↓	↓	↓	↓	↓	↓
Bed 1 Low CO_2 2mm	4	9	510	1	510	↓	↓	↓	↓	↓	↓	↓	↓
Bed 1 Low flow 250	5	6	250	1	250	↓	↓	↓	↓	↓	↓	↓	↓

$\left(\frac{H_{CO_2}\,IN}{F}\right)\left(\frac{P_{CO_2}CAL}{H_{CO_2}CAL}\right)$

	FEED CO_2	MMHG		FEED H_2O PK HT	FEED H_2O D.P. F	MM HG	CYCLE # DATE	TEMPERATURE ROLL	TEMPERATURE FT	COMPOSITION ROLL	COMPOSITION FT
1	(17.2)(2.72) / (1)(16.8)	2.79		14.5	50	9.3	11-3-71		77		40
2	(16.1)(2.72) / (1)(15.6)	2.80		14.1	50	9.3	11-3-71		76		34
3	(27.0)(2.72) / (1)(15.6)	4.69		12.6	50	9.3	11-3-71		75		31
4	(10.6)(2.72) / (1)(15.5)	1.86		13.5	50	9.3	11-3-71		75		26
5	(15.1)(2.78) / (1)(15.5)	2.65		13.5	50	9.3	11-3-71		74		24

ATTENUATOR

CALIB	READ	F
2	2	1
2	1	2
2	4	.5
1	1	1
1	2	.5
4	2	2
4	1	4

10 →	1	2	3	4	5		1	2	3	4	5
	CO_2	CO_2	CO_2	CO_2	CO_2		H_2O	H_2O	H_2O	H_2O	H_2O
MG	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1) TOTAL AREA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
(2) AREA BYPASS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(3) AREA ADS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(4) TOTAL CALC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$\frac{(3)}{(4)}$ x100 = % REMOVAL EFF $\bar{E}$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTE: CALCULATIONS BELOW ASSUME T GAS = [illegible] C

CO_2 CAPACITY

RUN ID	RUN	10^{-5}	[illegible]	P_{CO_2} MMHG	$\bar{E}_{CO_2}$ %	FLOW ML/MIN (L)	TIME MIN / VOL ML (L)	=	GM / L	VOL ML (L) / WT GM (KG)	=	% / WT
P7481 Bed 2 Nom.	1	10^{-5}	[illegible]	2.79	32.7 / 31.8	510	45/30 / 5	9.63 / 7.61	GM / L	5 / 1.98	2.43 / 1.92	% / WT
Hi Flow	2	10^{-5}	[illegible]	2.80	17.6 / 13.3	1000	45/30 / 5	9.33 / 7.02	GM / L	5 / 1.99	2.23 / 1.76	% / WT
Hi CO_2	3	10^{-5}	[illegible]	4.69	24.4 / 19.4	510	45/30 / 5	9.92 / 8.40	GM / L	5 / 1.98	2.50 / 2.12	% / WT
Low CO_2	4	10^{-5}	[illegible]	1.86	41.5 / 32.6	510	45/30 / 5	6.58 / 5.59	GM / L	5 / 1.98	1.67 / 1.41	% / WT
Low flow	5	10^{-5}	[illegible]	2.65	41.7 / 33.0	250	45/30 / 5	4.66 / 3.93	GM / L	5 / 1.99	1.17 / .992	% / WT

H_2O CAPACITY	RUN	10^{-5}	[illegible]	P_{H_2O} MMHG	$\bar{E}_{H_2O}$ %	FLOW ML/MIN (L)	TIME MIN / VOL ML (L)	=	GM / L	VOL ML (L) / WT GM (KG)	=	% / WT
P7481 Bed 2 Nom.	1	10^{-5}	[illegible]	9.3	63.0 / 52.9	510	45/30 / 5	21.7 / 17.3	GM / L	5 / 1.98	5.47 / 4.37	% / WT
Hi Flow	2	10^{-5}	[illegible]	9.3	30.1 / 22.1	1000	45/30 / 5	17.9 / 16.2	GM / L	5 / 1.98	4.50 / 4.09	% / WT
Hi CO_2	3	10^{-5}	[illegible]	9.3	60.5 / 48.3	510	45/30 / 5	19.9 / 16.6	GM / L	5 / 1.98	5.01 / 4.19	% / WT
Low CO_2	4	10^{-5}	[illegible]	9.3	61.5 / 49.1	510	45/30 / 5	20.2 / 16.9	GM / L	5 / 1.98	5.10 / 4.26	% / WT
Low flow	5	10^{-5}	[illegible]	9.3	66.0 / 74.6	250	45/30 / 5	15.0 / 11.6	GM / L	5 / 1.98	3.78 / 2.92	% / WT

TABLE IV

SORBENT EVALUATOR CALCULATION SHEET

USE FLOW IN LITERS/MIN OR ML/MIN; WT IN KG OR GM; VOL IN LITERS OR ML

SAMPLE IDENTIFICATION		RAW FLOW RDG	CAL FLOW	FACTOR (.3 FOR CFM, 1/2 FOR CFH)	FLOW LITERS/MIN ML/MIN	ADSORPTION PRESS IN HG	ADSORPTION AIR INLET T F	ADSORPTION WATER TEMP F	DESORPTION WATER TEMP F	DESORPTION PRESS. IN HG OR μ	DESORPTION TIME MIN	ADSORPTION TIME MIN	ADSORPTION CALC TIME MIN
Low CO_2 Bed 1	6	9	510	1	510	28	75	75	75	30μ	45	45	45/30
60° D.P. Bed 1	7	9	510	1	510						45	45	45/30
40° DP Bed 1	8	9	510	1	510						45	45	45/30
30 min ½ cycle	9	9	510	1	510						30	30	30
Nominal Bed 1 P-7481	10	9	510	1	510						45	45	45/30

$(P_{CO_2}\ IN)(P_{CO_2}CAL)$ / $(F)(H_{CO_2}CAL)$		FEED CO_2		MMHG		FEED H_2O PRESS	FEED H_2O D.P. F	MM HG	CYCLE # / DATE	TEMPERATURE ROLL	TEMPERATURE FT	COMPOSITION ROLL	COMPOSITION FT
	6	24 / 1	2.72 / 15.5	.42	—	13.5	50	9.3	11-5-71		72		21
	7	16.5 / 1	2.72 / 15.7	2.86	—	19.0	60	12.8	11-5-71		70		14
	8	16.8 / 1	2.72 / 15.7	2.91	—	8.8	40	6.3	11-5-71		69		12
	9	15.1 / 1	2.72 / 15.6	2.63	—	13.0	50	9.3	11-5-71				84
	10	17.5 / 1	2.72 / 15.6	3.05	—	14.0	50	9.3	11-8-71				07

ATTENUATOR

CALIB	READ	F
2	2	1
2	1	2
2	4	.5
1	1	1
1	2	.5
4	2	2
4	1	4

10 →	CO_2	CO_2	CO_2	CO_2	CO_2		H_2O	H_2O	H_2O	H_2O	H_2O
MG	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1) TOTAL AREA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(2) AREA BYPASS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(3) AREA ADS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(4) TOTAL CALC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(3)/(4) x100 % REMOVAL EFF Σ	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTE: CALCULATIONS BELOW ASSUME TCAN [illegible]

CO_2 CAPACITY

RUN ID	CAN	MMHG	Σ CO_2	FLOW ML/MIN	TIME MIN		VOL S / WT	=	WT
Low CO_2 Bed 1	6	0.42	81.4 / 75.0	510	45/30 / 5	3.42 / 2.48	5 / 1.98	.865 / .626	
60° DP Bed 1	7	2.86	32.8 / 25.6	510	45/30 / 5	7.95 / 6.78	5 / 1.98	2.01 / 1.71	
40° DP Bed 1	8	2.91	30.0 / 83.0	510	45/30 / 5	7.26 / 6.31	5 / 1.98	1.84 / 1.59	
30 min ½ cycle	9	2.63	23.3	510	30 / 5	4.45	5 / 1.98	1.126	
Nominal Bed 1 P7481	10	3.05	35.1 / 27.7	510	45/30 / 5	9.16 / 7.75	5 / 1.98	2.32 / 1.95	

H_2O CAPACITY

RUN ID	CAN	MMHG	Σ H_2O	FLOW ML/MIN	TIME MIN		VOL S / WT	=	WT
Low CO_2	6	9.3	65.5 / 50.7	510	45/30 / 5	20.9 / 17.1	5 / 1.98	5.27 / 4.32	
60° DP	7	12.8	66.5 / 55.0	510	45/30 / 5	31.1 / 25.1	5 / 1.98	7.85 / 6.34	
40° DP	8	6.3	64.6 / 50.3	510	45/30 / 5	14.0 / 12.0	5 / 1.98	3.54 / 3.04	
30 min ½ cy	9	9.3	63.9	510	30 / 5	17.5	5 / 1.98	4.41	
Nom Bed 1 P7481	10	9.3	65.5 / 53.7	510	45/30 / 5	22.1 / 18.0	5 / 1.98	5.57 / 4.55	

TABLE IV
(CONTINUED)

SORBENT EVALUATOR CALCULATION SHEET

USE FLOW IN LITERS/MIN OR ML/MIN WT IN KG GM VOL IN LITERS ML

SAMPLE IDENTIFICATION		RAW FLOW RDG	CAL FLOW	FACTOR 28.3 FOR CFM 472 FOR CFH	FLOW LITERS/MIN ML/MIN	ADSORPTION PRESS IN HG	ADSORPTION AIR INLET T F	ADSORPTION WATER TEMP F	DESORPTION WATER TEMP F	DESORPTION PRESS. IN HG OR μ	DESORPTION TIME MIN	ADSORPTION TIME MIN	ADSORPTION CALC TIME MIN
High ads T 98°	11	9	510	1	510	28	75	98	78	30μ	45	45	45/30
Low ads T 67°	12	9	510	1	510	28	75	67	67	30μ	45	45	45/30
1½ hr halfcycle	13	9	510	1	510	28	75	75	75	30μ	90	90	90

	ID	FEED CO_2		MMHG		FEED H_2O		MM HG	CYCLE # DATE	TEMPERATURE ROLL	TEMPERATURE FT	COMPOSITION ROLL	COMPOSITION FT
$(\%CO_2\ IN)(\%CO_2CAL)$ / $(F)(\%CO_2CAL)$	11	16.5 / 1	2.72 / 15.7	2.86		13.3	50	9.3					57
ATTENUATOR	12	17.6 / 1	2.72 / 15.7	3.04		14.0	50	9.3					41
	13	16.8 / 1	2.72 / 15.0	3.04		13.0	50	9.3					69

CALIB	READ	F
2	2	1
2	1	2
2	4	.5
1	1	1
1	2	.5
4	2	2
4	1	4

ID →	11	12	13			11	12			
	CO_2	CO_2	CO_2	CO_2	CO_2	H_2O	H_2O	H_2O	H_2O	H_2O
MG										
(1) TOTAL AREA	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			
(2) AREA BYPASS	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			
(3) AREA ADS	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			
(4) TOTAL CALC	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			
$\frac{(3)}{(4)}$ x100 % REMOVAL EFF	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			

NOTE: CALCULATIONS BELOW ASSUME TGAS [illegible] C

CO_2 CAPACITY RUN ID	CAN	10^{-5}	2.36	P_{CO_2} IN MMHG	% CO_2	FLOW ML/MIN L	TIME MIN / VOL ML L		GM / L	VOLS ML L / WT GM KG	=	% WT
High ads T	11	10^{-5}	2.36	2.86	36.4 / 27.7	510	45/30 / 5	8.60 / 7.54	GM / L	5 / 1.98	2.18 / 1.91	% WT
Low ads T	12	10^{-5}	2.36	3.04	30.7 / 23.6	510	45/30 / 5	7.79 / 6.76	GM / L	5 / 1.98	1.97 / 1.71	% WT
1½ hr halfcycle	13	10^{-5}	2.36	3.04	16.25	510	90 / 5	10.0	GM / L	5 / 1.98	2.53	% WT
		10^{-5}	2.36						GM / L	VOL		% WT
		10^{-5}	2.36						GM / L	VOL		% WT

H_2O CAPACITY		10^{-5}	2.962	P_{H_2O} IN MMHG	% H_2O	FLOW ML/MIN	TIME MIN / VOL ML L		GM / L	VOLS ML L / WT GM KG	=	% WT
High Ads T	11	10^{-5}	2.962	9.3	42.3 / 32.5	510	45/30 / 5	13.3 / 11.6	GM / L	5 / 1.98	3.36 / 2.93	% WT
Low ads T	12	10^{-5}	2.962	9.3	72.5 / 66.1	510	45/30 / 5	27.2 / 19.9	GM / L	5 / 1.98	6.86 / 5.03	% WT
1½ hr half cycle	13	10^{-5}	2.962	9.3	27.1	510	90 / 5	22.3	GM / L	5 / 1.98	5.63	% WT
		10^{-5}	2.962						GM / L	VOL		% WT
		10^{-5}	2.962						GM / L	VOL		% WT

TABLE IV
(CONTINUED)

CO_2 Feed Concentration

At high levels of P_{CO_2} (5 mm) the cyclic capacity for CO_2 was unaffected by the P_{CO_2} (Figure 4). From 3 mm downward the CO_2 cyclic capacity fell almost linearly with P_{CO_2}. This effect resulted from the existence of an equilibrium between the rate of adsorption and the rate of spontaneous desorption as the bed approaches saturation. The rate of adsorption was increased as P_{CO_2} increases but only in proportion to the adsorption sites which remained unoccupied. The rate of desorption increased with the number of occupied sites. As P_{CO_2} rises, most of the sites become filled and when spontaneous desorption did occur, a sufficiently high P_{CO_2} level (above 3 mm) caused rapid readsorption, keeping practically all the sites occupied.

The water capacity showed no clear dependence on CO_2 partial pressure, which is consistent with the proposed HS-C model.

Additional capacity was available for both water and CO_2 as the adsorption continued from 30 to 45 minutes. Later results (Figure 8) show there was little capacity to be gained after 45 minutes, even with correspondingly increasing desorption time.

Dew Point

Dew point had a large effect on H_2O capacity. When 45 minutes of adsorption was measured the capacity increased from 3.5% to 8% as dew point changed from 40°F to 60°F (Figure 5). This effect is important in maintaining cabin dew point as the water latent load increases.

CO_2 capacity is little affected with humidity, showing curious but repeatable slight maximum peaks at 50°F dew point.

Adsorption/Desorption Temperature

CO_2 capacity depends little on temperature (Figure 6). Water capacity is significantly affected, with water capacity at 97°F down to 1/2 or 2/3 that of 67°F. This effect is not understood, but doubtless arises because of the net change with temperature of the overall rates of adsorption and desorption.

Inlet Flow Rate

Inlet flow rate can affect capacity in two ways: (1) as flow increases a better mass transfer coefficient might improve mass transfer rate and thus capacity during a given time; (2) as flow increases more of the constituent to be adsorbed is passed through the bed and thus more may be available at the rear of the bed, again affecting the average rate of adsorption and thus capacity during a given time (Figure 7).

It is difficult to separate the two effects, but it seems clear that at gas flow rates over 500 ml/min., mass transfer is not limiting -- the data indicate a capacity decrease with increasing flow rate. A decrease seems impossible, and may perhaps be a result of unresolved test apparatus inaccuracy.

At low flow rates the second effect is clearly operative -- capacity falls linearly with flow for both water and CO_2.

Cycle Time

Long cycle times allow generous contact with gases to be absorbed, and desorption from deep within the particles within the bulk of the bed. Shorter cycle times permit only incomplete desorption; in fact, casual observation has established that water apparently is desorbed before CO_2. On this basis the CO_2 curve of Figure 8 has been shaped to show the low capacity for CO_2 at short cycle times. Alternately, water capacity is shown rising sharply with increasing cycle time.

At 45 minutes half-cycle time essentially all the CO_2 and water capacity available has been used, for a further increase in half-cycle time gave no important capacity increase. At 30 minutes the capacity for CO_2 was down by 50%. This effect was not nearly as strong in the large scale tests, probably due to the thinner half thickness of the bed (1-1/2 or 3/4 inch for large scale tests; 2 in. for small scale tests).

LARGE SCALE EQUIPMENT DESCRIPTION

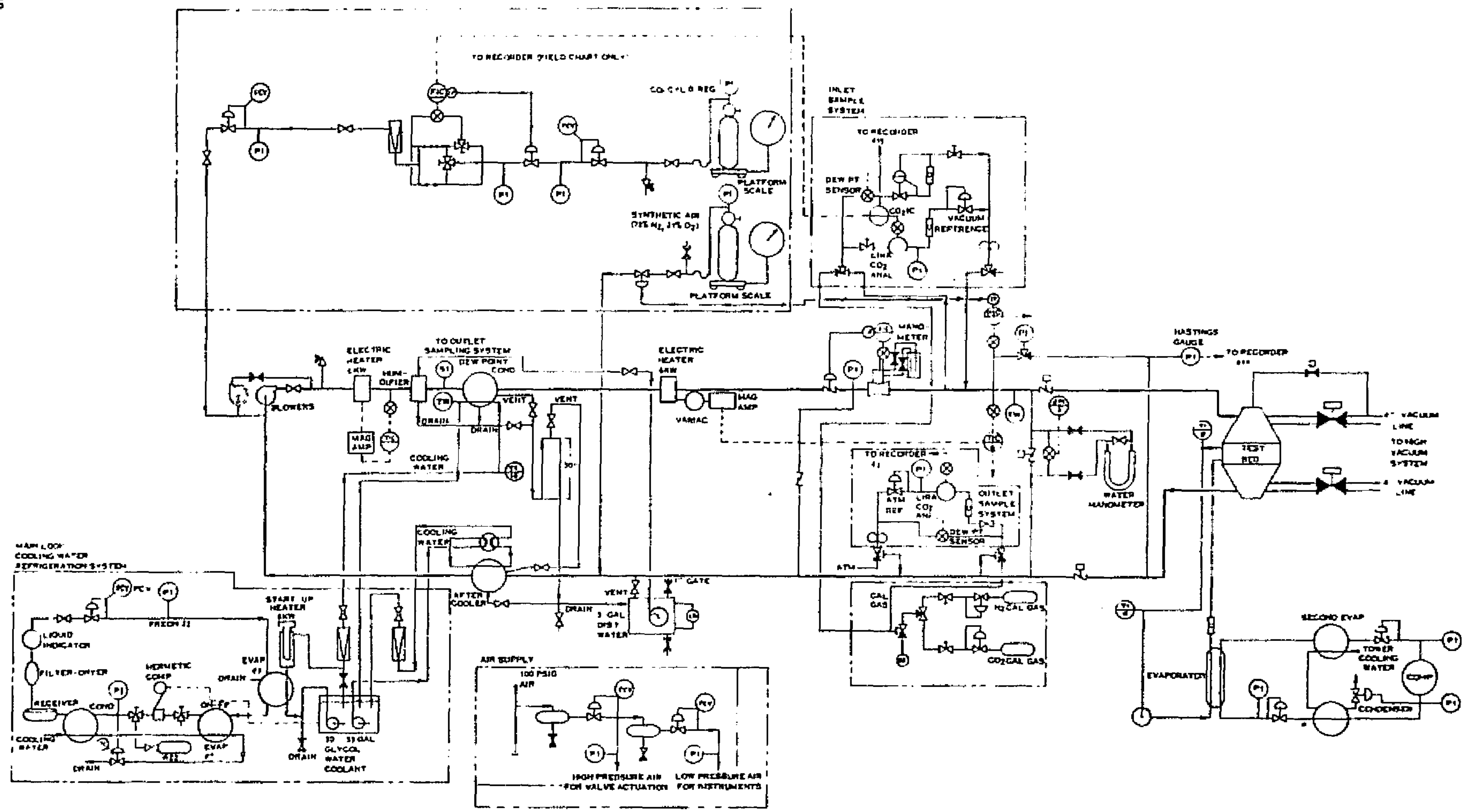
Hamilton Standard's test rig #88 was used for the large scale test program. Figure 29 shows the exact configuration of the rig. Unused sections of the rig which were valved off are not shown. Figure 30 shows the rig in block form, from which its functioning may more easily be understood.

The test rig provided a stream of air humidified to a constant dew point with pressure, flow rate, CO_2 partial pressure, and temperature under closed control. Controlled temperature water was supplied to the test canister to provide cooling during adsorption and heating during desorption. Figures 31 and 32 are photographs of the large scale rig.

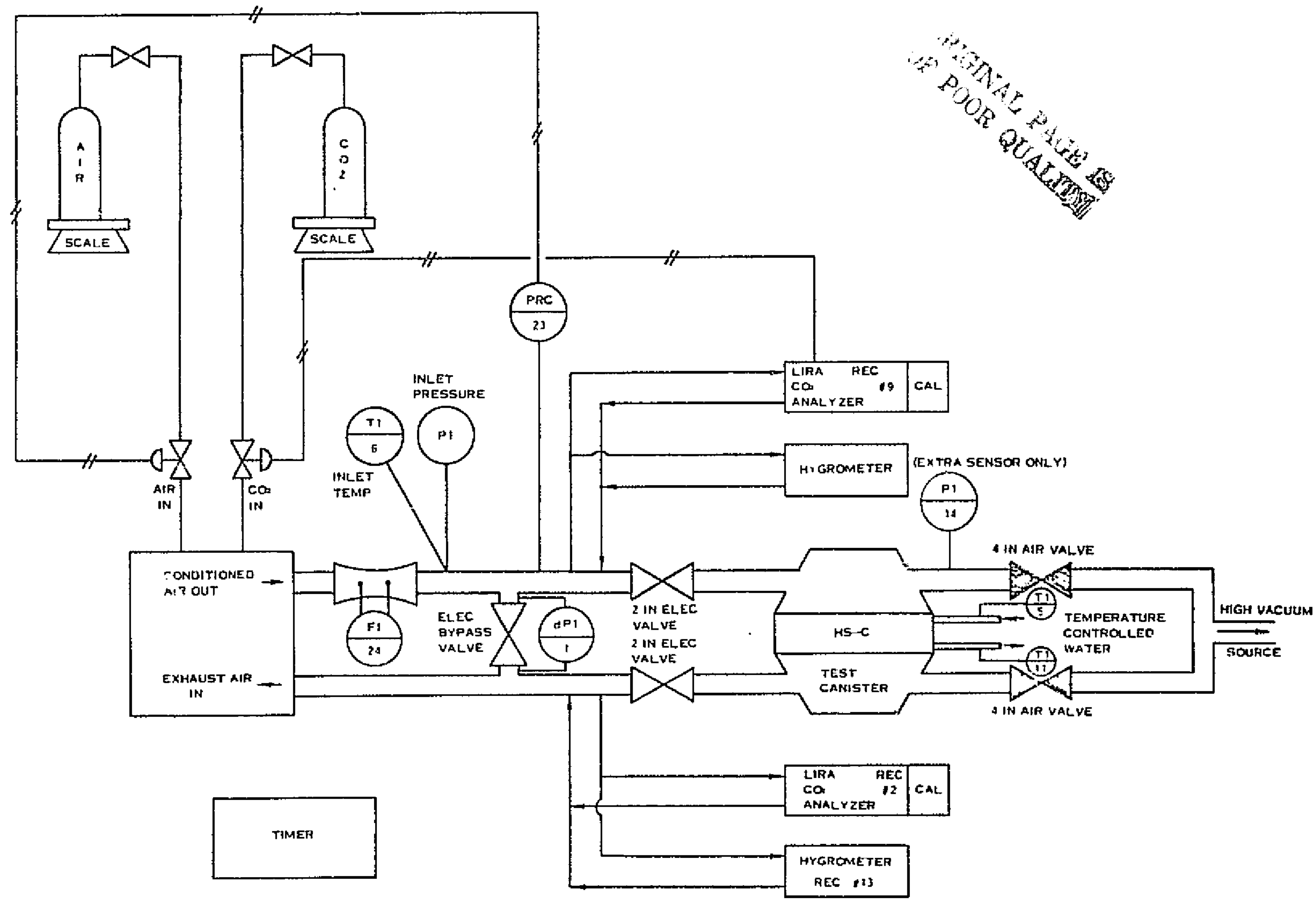
During adsorption (with valves as shown in Figures 29 and 30) CO_2 was automatically added to the system from a supply cylinder to maintain inlet

ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 29



CANISTER HEATING/COOLING SYSTEM



LARGE SCALE TESTS
RIG 88 BLOCK DIAGRAM

FIGURE 30

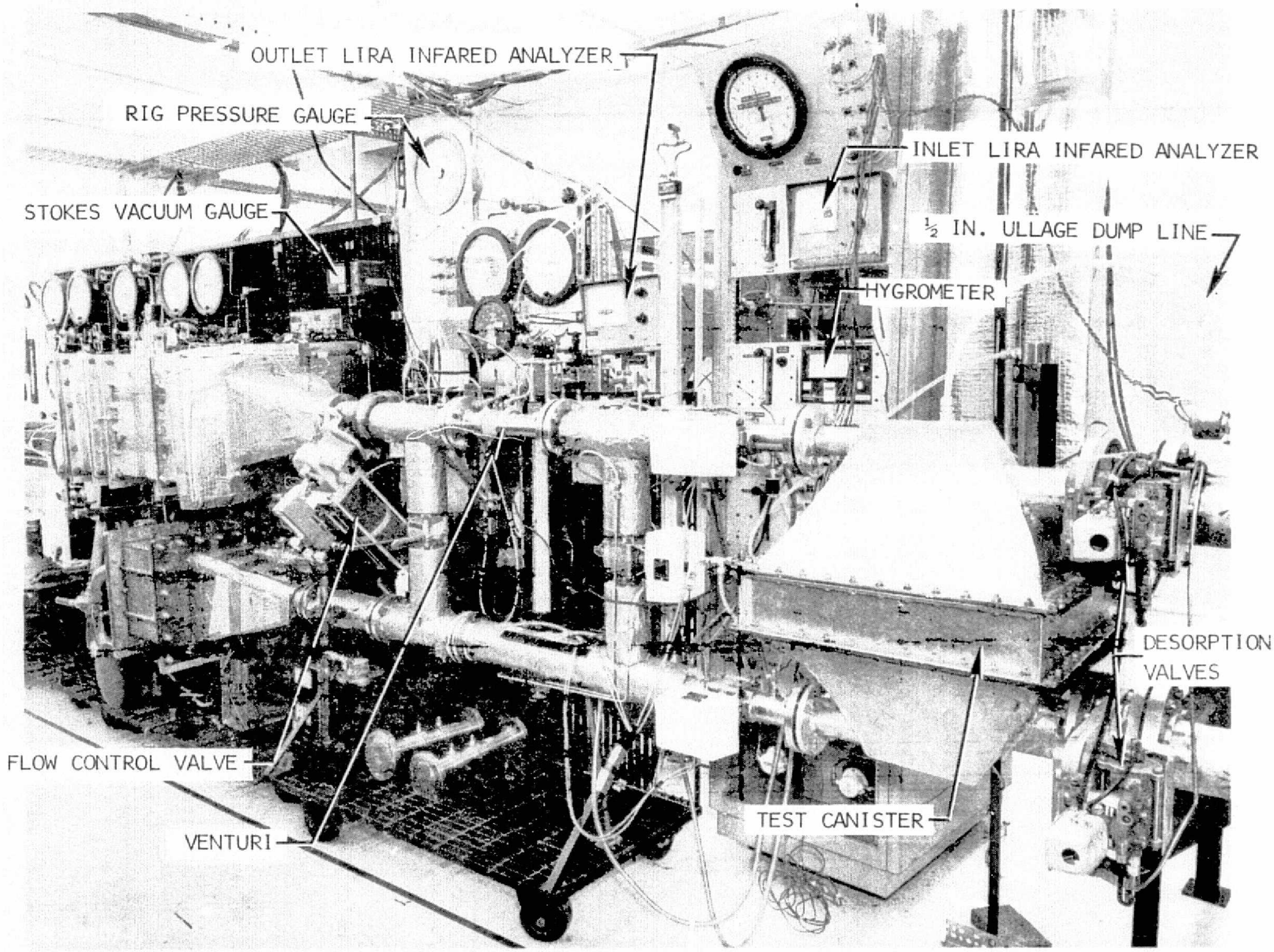


FIGURE 31

LARGE SCALE TEST APPARATUS

LARGE SCALE TEST APPARATUS

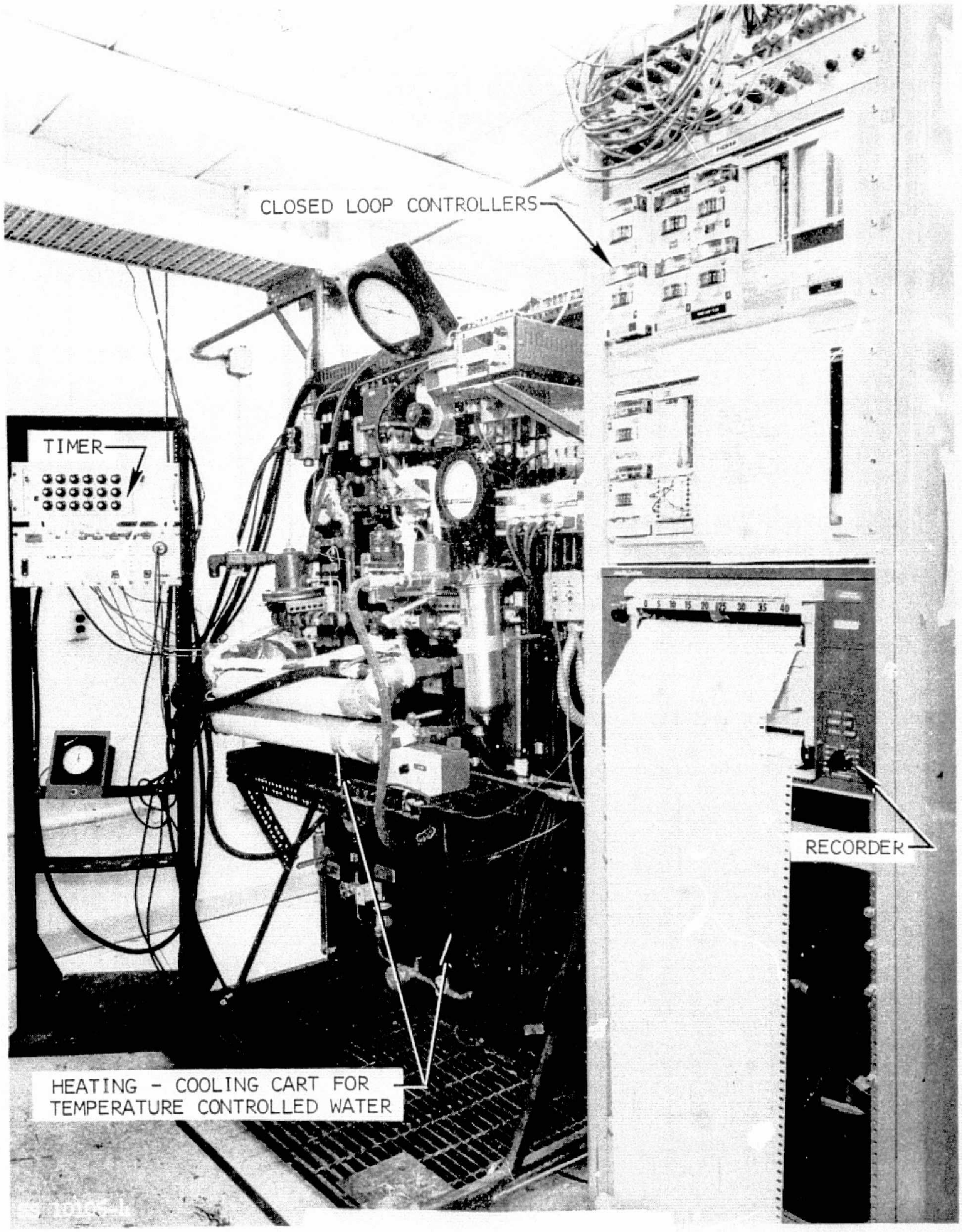


FIGURE 32

CO_2 partial pressure constant even though the capacity of the bed was high at the start of the adsorption and low at the end. Total pressure was maintained automatically by adding CO_2 free air from a cylinder as necessary to make up for ullage losses.

Automatic cycling was controlled by a flexible timer actuating test canister inlet valves and the large desorption valves which connected each side of the test bed to a high (10-100 micron) vacuum source. The air flow was bypassed rather than stopped during desorption to minimize disturbances within the test rig.

Large Scale Test Canister

The large scale test canister was constructed from a custom-sized commercial aluminum heat exchanger fitted with custom-made aluminum transition sections. The heat exchanger drawing is shown in Figure 33 and the transition sections as Figure 34.

HS-C was held loaded in the 0.1 inch sections between the 14 in. x 3 in. fins of the heat exchanger and retained by an 80 mesh screen on each side of the heat exchanger. Each screen was held in place with aluminum honeycomb material (1 in. thick with 3/8 in. hexagonal holes), in turn supported with two 1/2 in. rods across one dimension of the exchanger. Flow was downward through the exchanger. Photographs of the installed canister and the open canister ready for loading, are shown in Figures 10, 31, and 9. The assembly is shown mounted on the test rig, with the large desorption valves visible on the right and the motorized valves associated with the adsorption flow on the left. Screens and their supports are not visible. Note the ruler added to show the scale of the equipment in both Figures 9 and 10.

Test Parameters

All test parameters were automatically recorded on a single strip chart except for CO_2 and air cylinder weights, which were recorded manually. Test parameters are listed in Table V.

Flow Pattern

During the test program, there was a lingering doubt that all the HS-C material had sufficient contact with the air stream. Perhaps there were areas behind the coolant tubes which did not have enough air flow.

Reynolds number for the bed was calculated as 5, assuming a particle size of 26 mesh. Using electrically conductive paper as an analog of the air passage, the flow pattern was predicted by constructing perpendiculars to lines of constant voltage which were located experimentally. The resultant flow pattern about one tube is shown as Figure 35. Clearly, a satisfactory flow was obtained around the tubes.

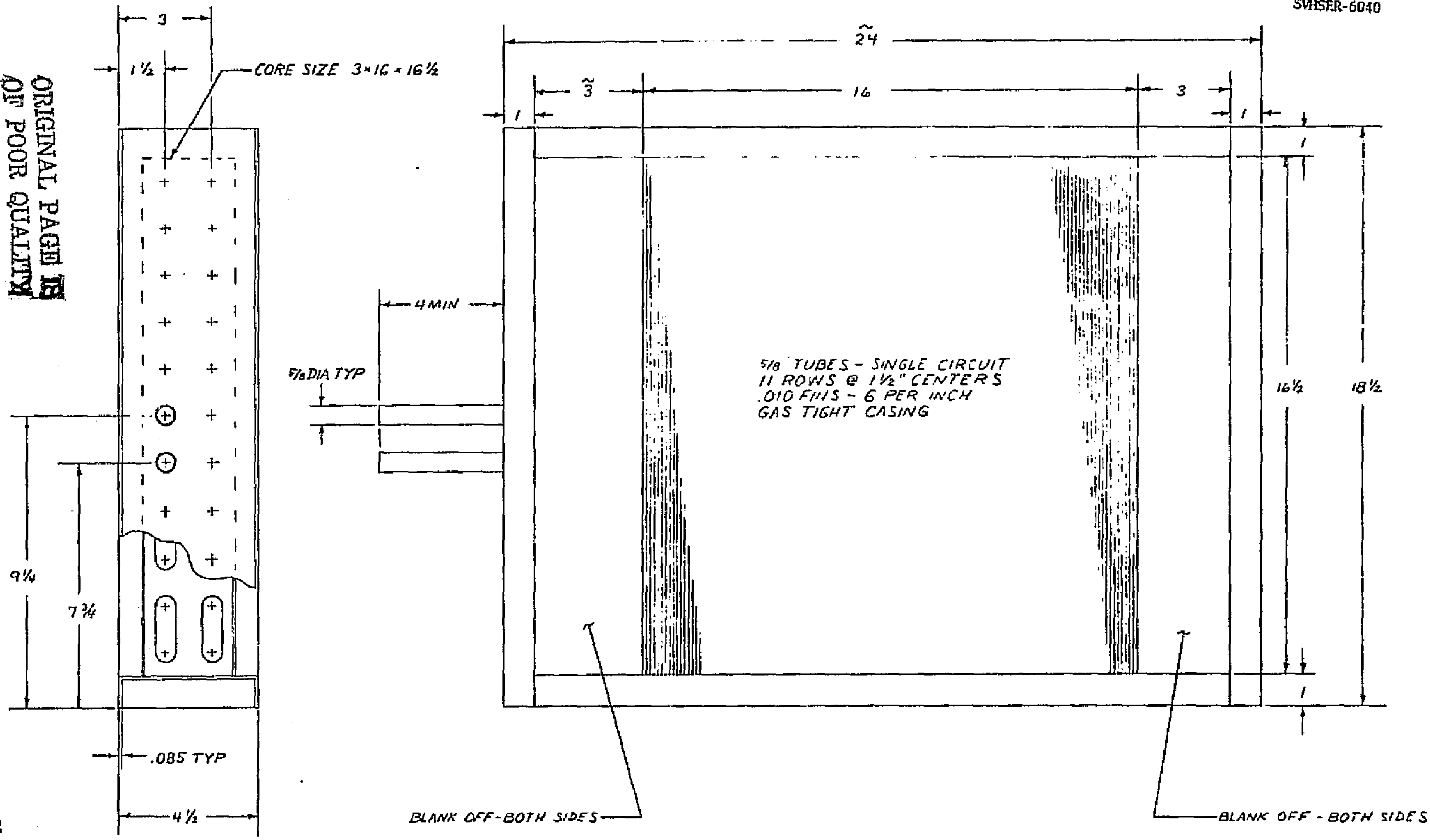
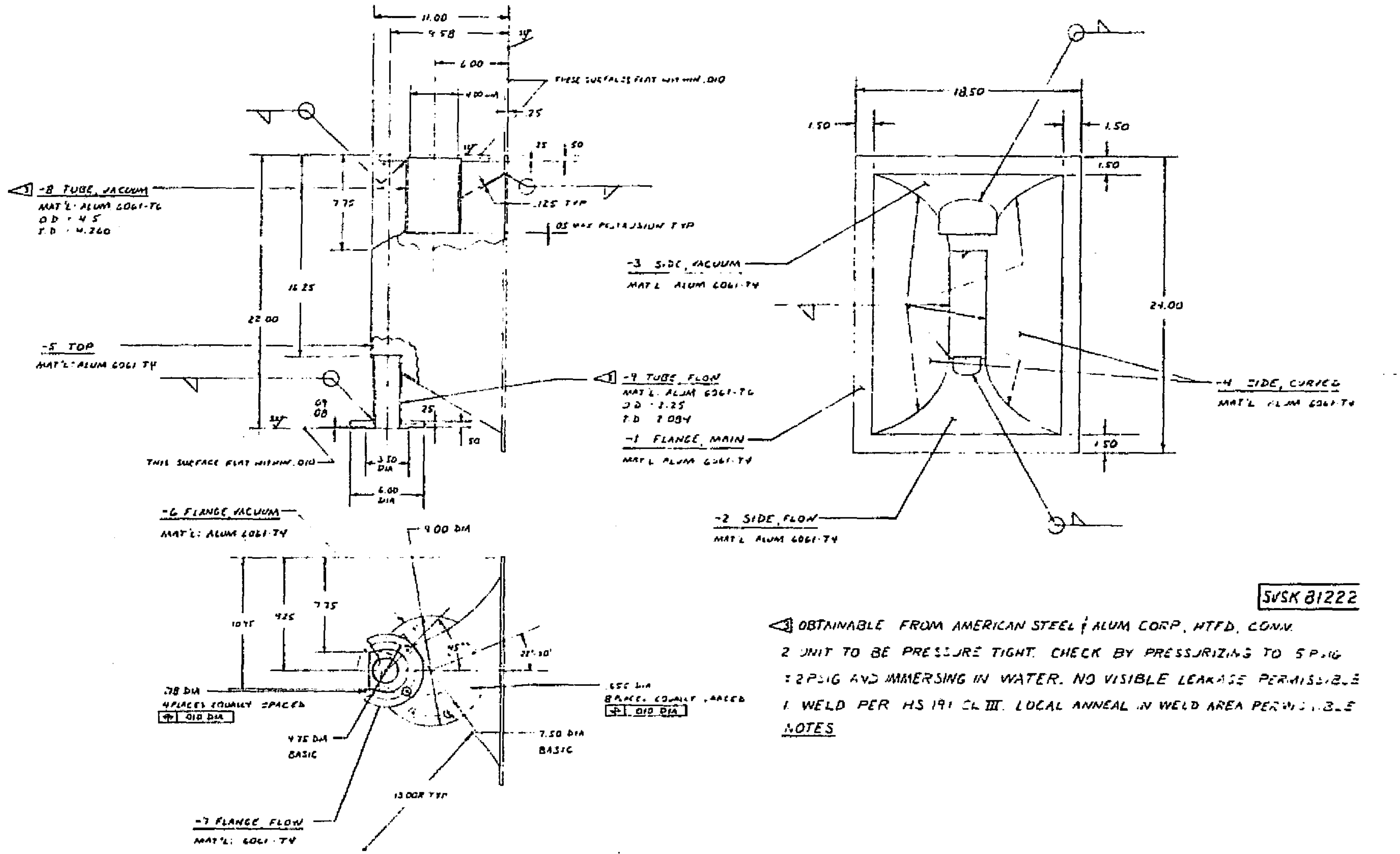


FIGURE 33

TEST CANISTER DESIGN LAYOUT

FIGURE 34



TEST CONFIGURATION HEADER LAYOUT

LARGE SCALE TESTS
FLOW PATTERN WITHIN HEAT EXCHANGER USED AS HS-C
CANISTER AS PREDICTED FROM ELECTRICAL ANALOG

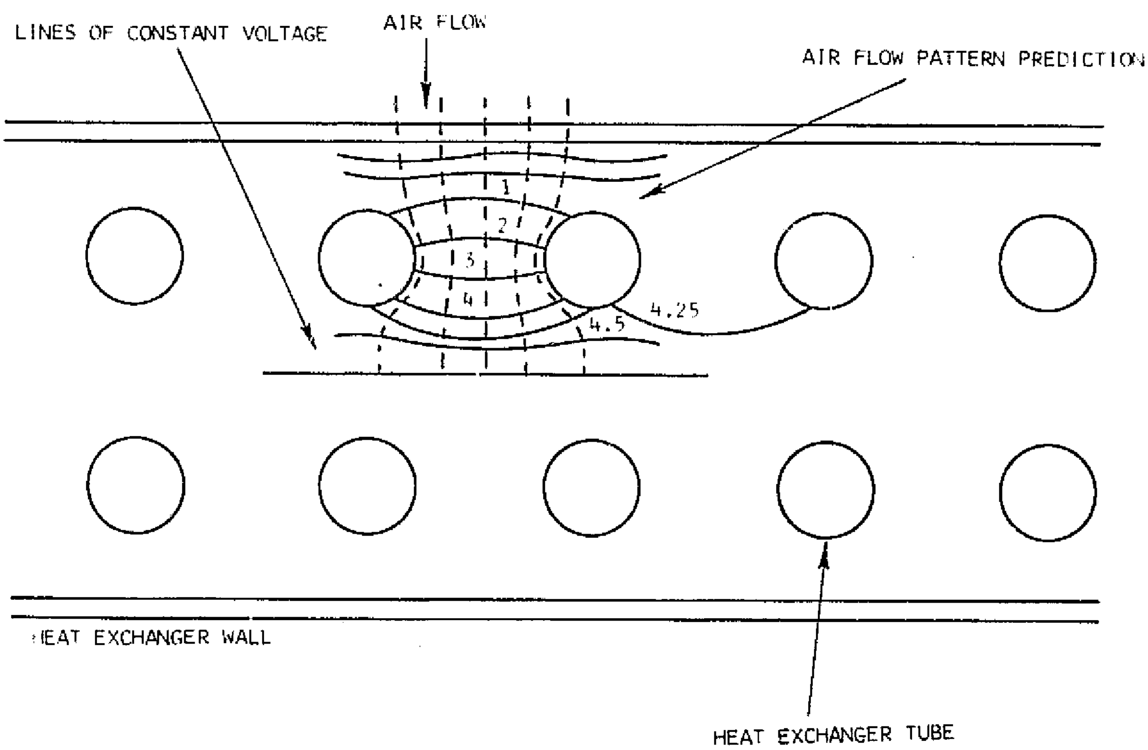


FIGURE 35

TEST PARAMETERS

Recorder Point No.	Signal Type	Logged Units	Description
1	Millivolt	in. H_2O	Canister pressure drop (DP cell)
2	Millivolt	mmHg	CO_2 partial pressure (outlet) (LIRA infared analyzer)
5	Thermocouple	°F	Canister coolant inlet
6	Thermocouple	°F	Air inlet temperature
9 or 15	Millivolt	mmHg	CO_2 partial pressure (inlet) (LIRA infared analyzer)
10	Thermocouple	°F	Dew point condenser coolant inlet temperature
11	Thermocouple	°F	Canister coolant outlet
13	Millivolt	°F	Dew Point (Cambridge 880 Hygrometer)
14	Millivolt	Microns	Canister Vacuum (Stokes-Hastings gauge)
23	Millivolt	psia	Loop pressure (DP cell)
24	Millivolt	cfm	Loop flow rate (DP cell)
		hours or minutes	Clock time -- noted on chart manually each hour. Chart moved at 10 in/hr.
		cycle no.	Logged manually on chart each cycle.
		CO_2 Weight Air Weight	
		ft. left on roll	Printed on chart.

A Texas Instrument recorder was used with copper-constantan thermocouples and chart paper WTT20 (0-200°F). Millivolt signals from analyzers and pressure transducers were also recorded on this paper but require a special linear scale for interpretation, as discussed below under "calibration."

TABLE V

Calibrations

All calibrations were made directly on the recorder without reference to intermediate dials and gauges.

Recorder Point no.	
1	Canister pressure drop was calibrated using a water manometer connected in parallel with the "DP" cell (delta pressure). The bypass valve was varied to produce a recorded pressure drop signal while water manometer readings were manually recorded. (See Figure 36). Accuracy was estimated as ±.1 in. H_2O.
2	LIRA infared analyzer. This unit was calibrated at least once every 8-12 hours with 1% and 0% span gas. Initial calibration included a midrange calibration gas, and resulted in Figure 37. Accuracy was estimated as ±0.1 mm CO_2.
5	Canister coolant inlet. Copper-constantan thermocouple, not calibrated, but there was agreement with #11 in no load condition, ±1°F.
6	Air inlet temperature. Copper-constantan thermocouple calibrated with a thermometer in the thermowell ±.5°F.
9	Inlet LIRA. See point #2 above.
10	Dew point condenser coolant inlet. Copper-constantan thermocouples cross checked with thermowell in coolant outlet ±1/2°F. (Flow was massive.)
11	Canister coolant outlet. Copper-constantan thermocouple, not calibrated but checked with #5 in no load condition ±1°F.
13	Cambridge 880 Hygrometer. The direct readout dial was calibrated on the rig by running in the bypass mode, reducing the flow until dew point would not decrease further, i.e., until the temperature leaving the dew point condenser was presumably equal to the condenser coolant temperature. Adequate humidification prior to this condenser was assured by noting that the dew point leaving the humidifier was higher by at least a few degrees than that leaving the dew point condenser. From this single point calibration a dial correction was obtained (±1°F) which was applied throughout the entire range. Final calibration was made by noting dial readings and recorded chart readings during a run, and plotting as in Figure 38.

LARGE SCALE TESTS
CANISTER PRESSURE DROP CALIBRATION
TRACE NO. 1 - BROWN

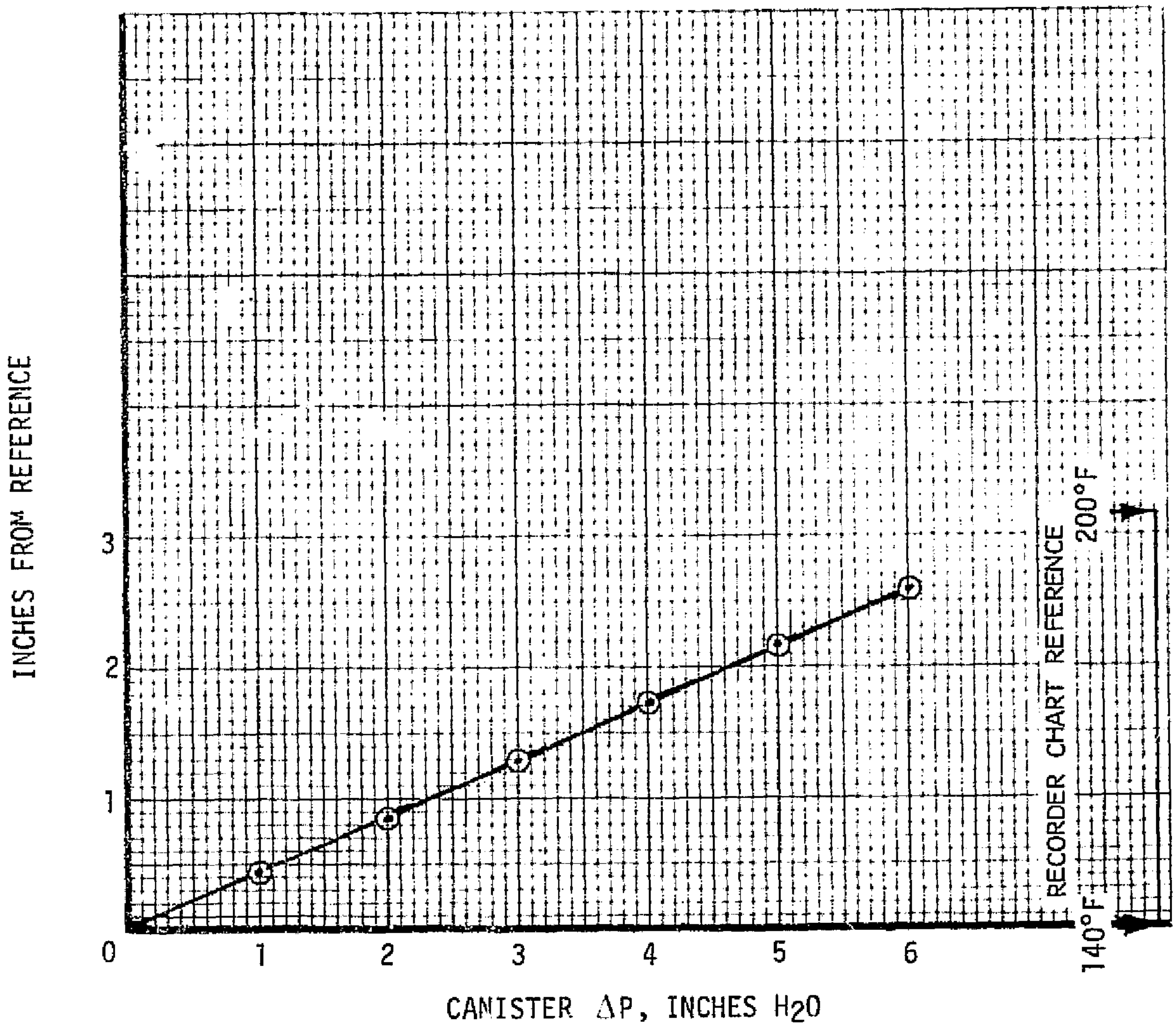


FIGURE 36

LARGE SCALE TESTS
P_{CO_2} CALIBRATION

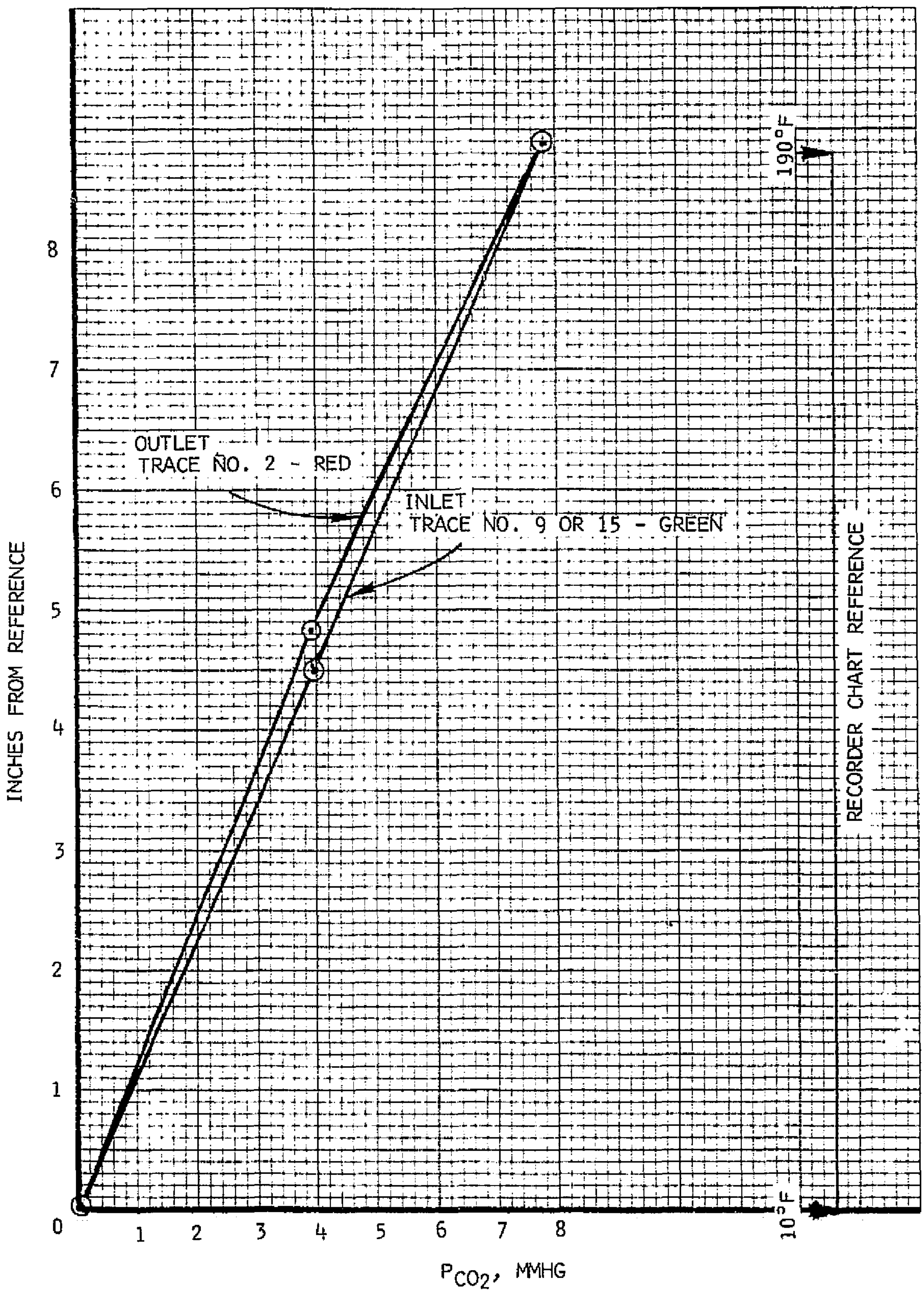


FIGURE 37

LARGE SCALE TESTS
DEW POINT CALIBRATION
TRACE NO. 13 - BROWN

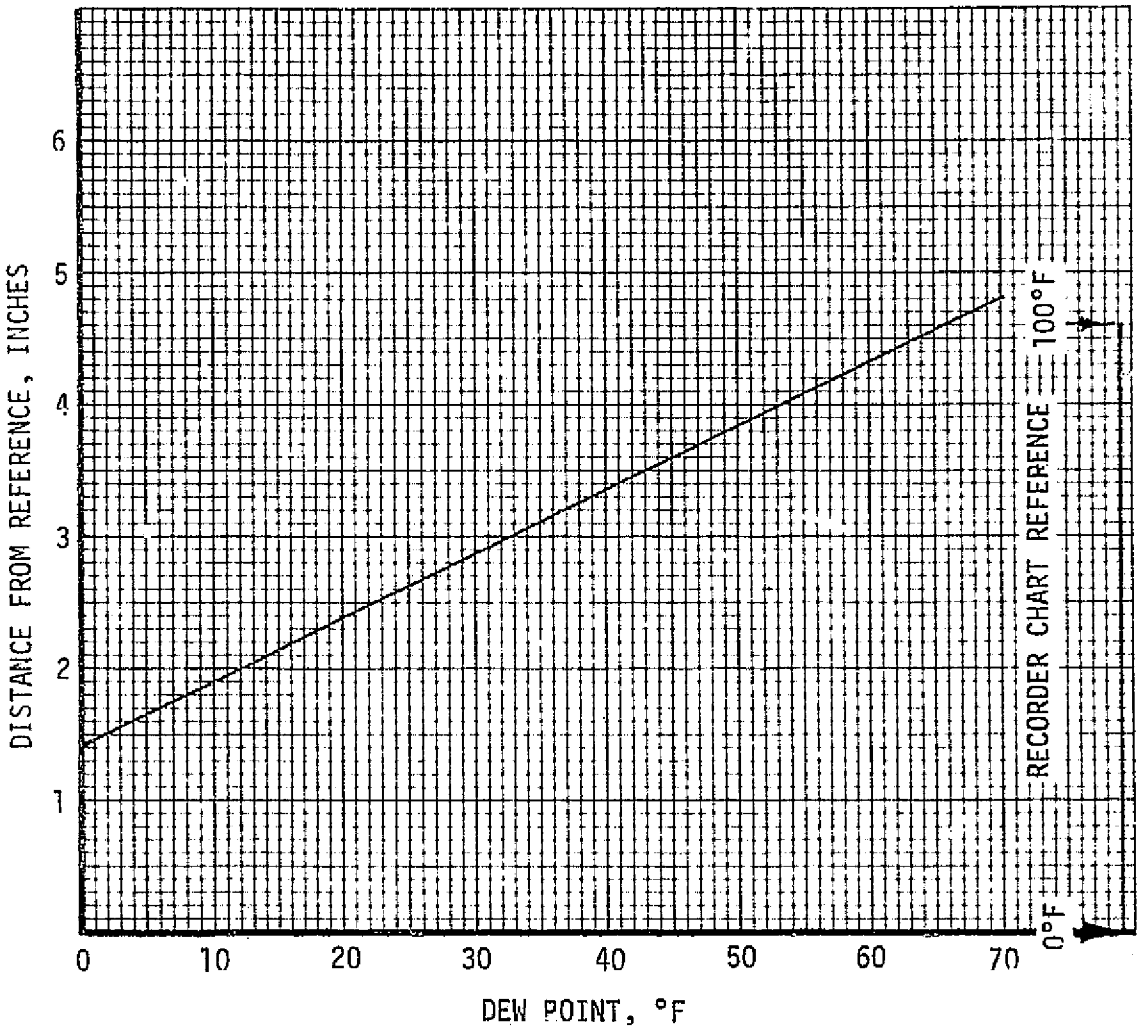


FIGURE 38

LARGE SCALE TESTS
HIGH VACUUM PRESSURE GAUGE CALIBRATION
TRACE NO. 14 - RED

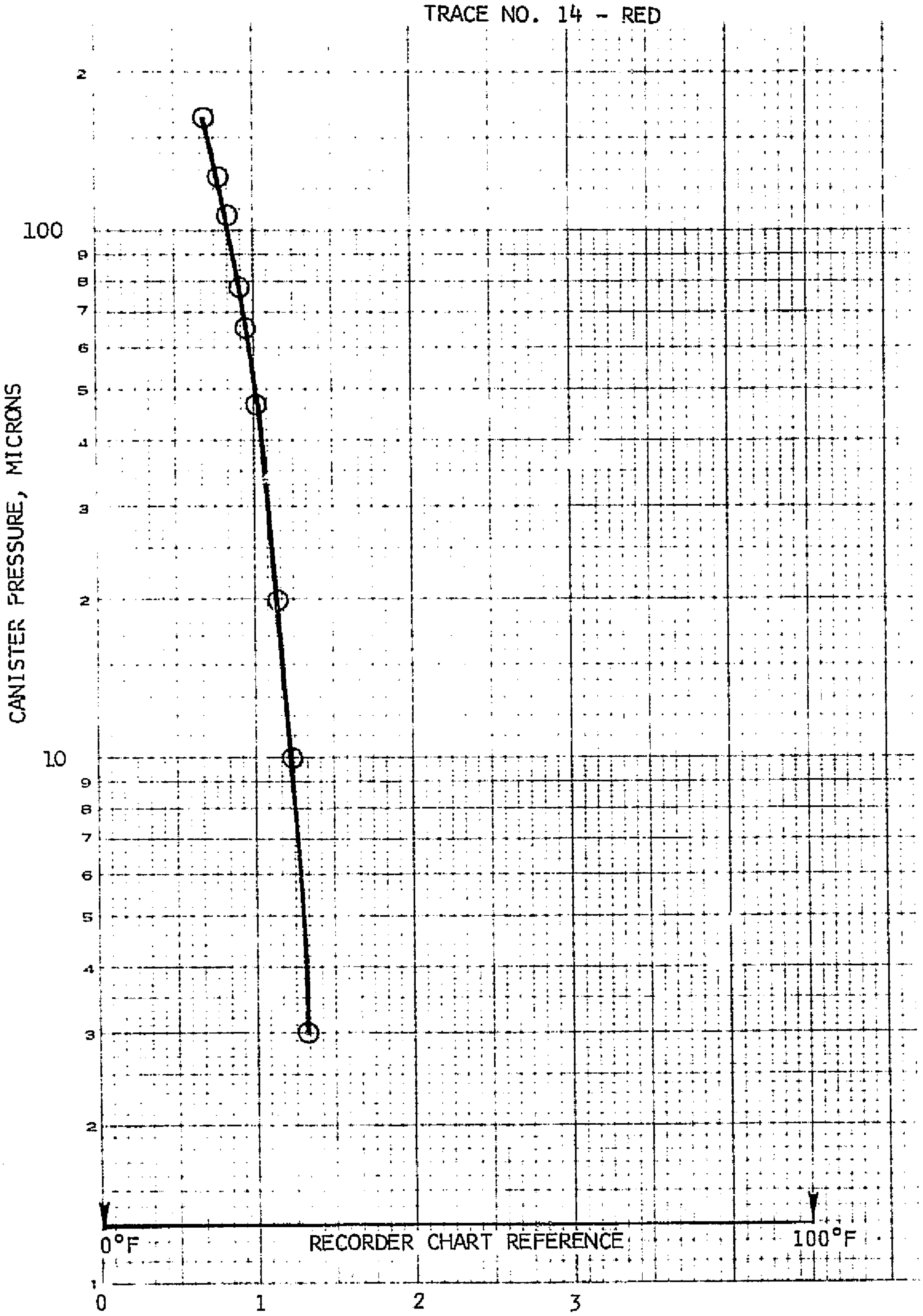


FIGURE 39

14 Canister vacuum (Microns). A Hastings thermocouple type vacuum sensor was wired into the recorder using the voltage applied to the local meter readout. A calibration curve (Figure 39) was made by noting recorded signals and meter readings. No direct calibration was made, but a general correspondence with similar gauges associated with the high vacuum system was noted.

23 Loop pressure. The zero pressure reference DP cell[1] recorded readout was calibrated by reference to a Wallace and Tiernan zero reference[1] ±0.1 psia (Figure 40).

24 Loop flow. Pressure drop across a venturi type flowmeter was measured with a DP cell and recorded. A water manometer was connected in parallel and the flow varied over the range of interest, noting recorder readings and manometer readings. Manometer readings were converted to flow (cfm) using charts derived from manufacturer's data, and plotted as Figure 41, which was used to read flows from the recorder.

As a cross check a dry test meter (gas meter type) was connected to the outlet flow and the inlet opened to atmospheric air. Flows measured in this manner are also shown in Figure 41.

LARGE SCALE TESTS

Objectives

The objectives of the large scale tests were:

- To establish the capacity of the HS-C bed for water vapor and CO_2 at full scale (4-man system);
- To establish the degradation, if any, to be expected of the HS-C material after 7 days continuous operation. This is a rough simulation of the 7-day shuttle mission;
- To explore the effect of several operating parameters on HS-C performance;
- To provide data for the design development tasks and for verification of the mathematical model of HS-C performance.

[1] one side permanently evacuated

LARGE SCALE TESTS
RIG PRESSURE CALIBRATION
TRACE NO. 23 - BLUE

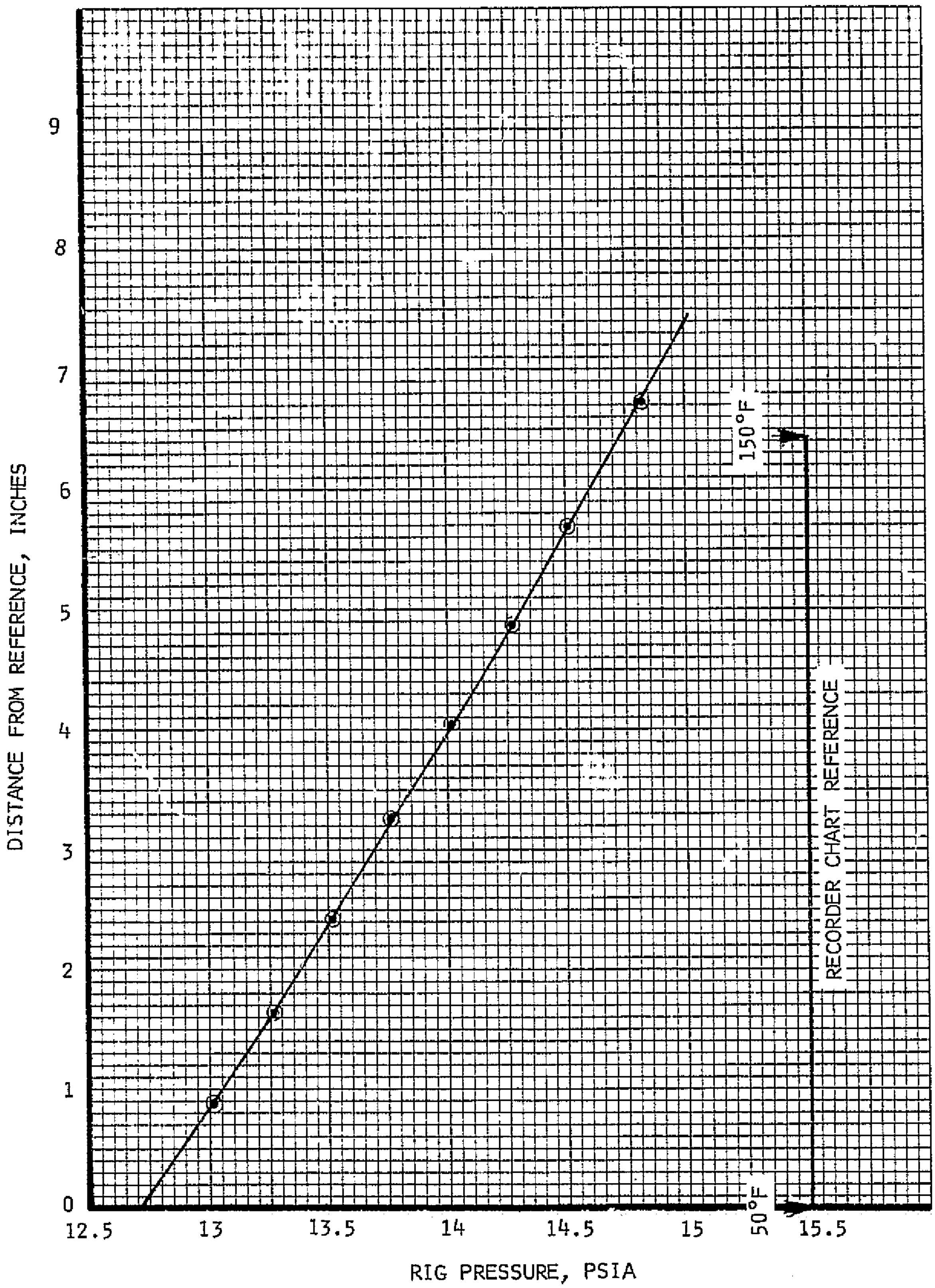


FIGURE 40

LARGE SCALE TESTS
AIR FLOW CALIBRATION
TRACE NO. 24 - BLACK

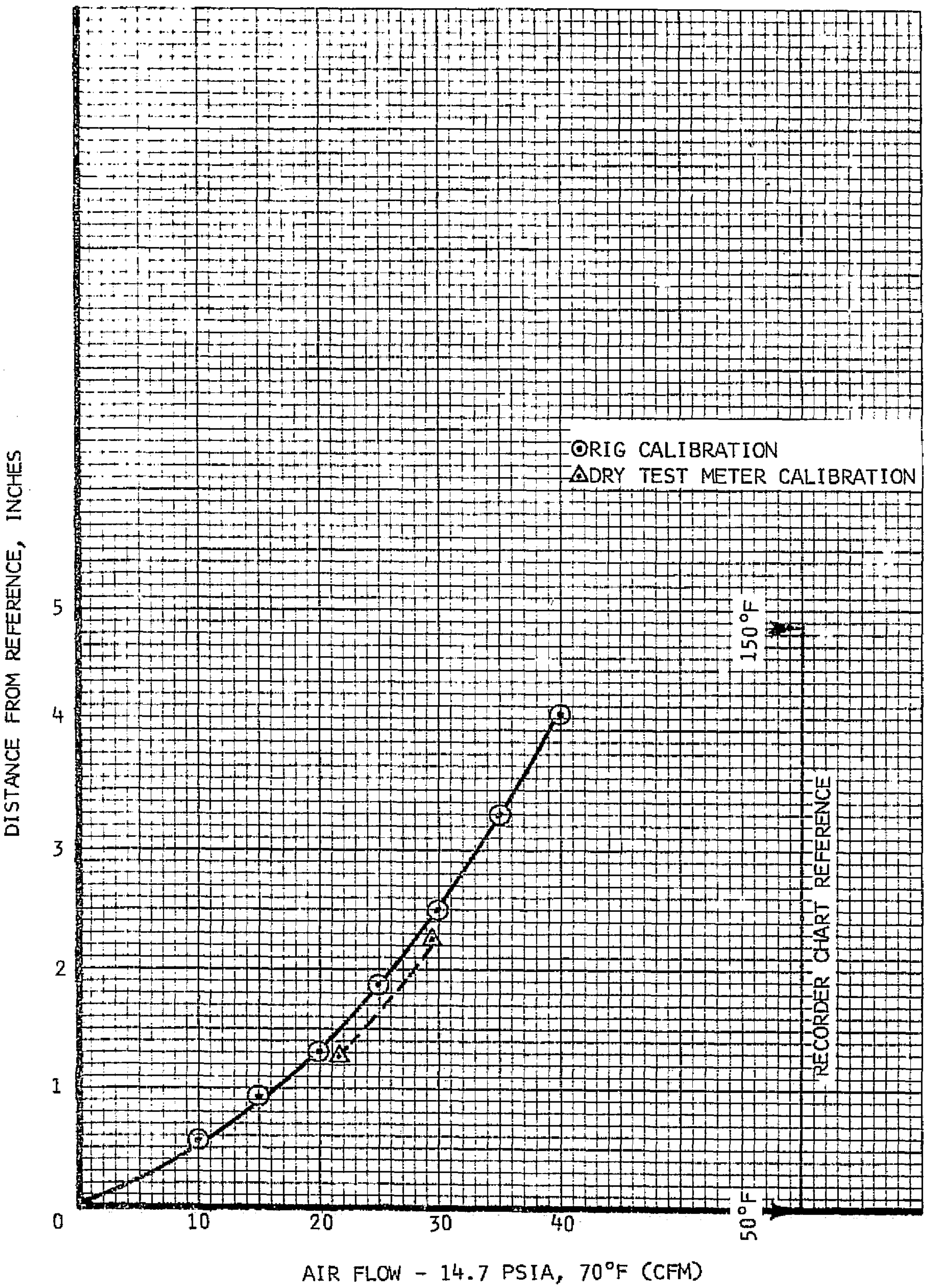


FIGURE 41

Experimental Method

Three separate series of tests were run according to the two test plans presented as Appendix E.

Series I used 8.84 pounds of 24-28 mesh HS-C and fulfilled the objectives of the large scale tests. Two hundred and nineteen hours of cyclic operation were accumulated without degradation including 7 continuous days (168 hours). Planned parametric test conditions were run, and complete data compiled. At nominal conditions (but with 5 mm CO_2 partial pressure, see below, page E-14) a CO_2 capacity of 2.0% by weight was indicated if a 90 minute desorption time was used.

Series II used a half bed (4.40 lbs.) of 24-28 mesh HS-C, thus decreasing the bed thickness from 3.0 to 1.5 inches to reduce the desorption time required for a 2.0% CO_2 adsorption capacity. Twenty-six hours of test were accumulated, and a CO_2 capacity of 1.9% by weight was achieved with a 40 minute desorption.

Series III also used a half bed of HS-C material, but smaller mesh size HS-C was used (30-40 mesh). A capacity of 2.0% CO_2 by weight was achieved with a 40 minute cycle, showing the enhancement of capacity made possible by the smaller particles of HS-C.

Water capacities for HS-C varied with the dew point, but better than 4.0% by weight was achieved with each HS-C material.

Data Summary

Data summary sheets made during test Series I, II and III are reproduced in Appendix F.

Calculations

The data recorded on the data sheets was complete except for water capacity. This was calculated by integration of the outlet dew point curve from the recorder chart. Figures 42 and 43 show the procedure.

First the recorder chart curve was transferred to graph paper with a point every 5 minutes. This curve was replotted as P_{H_2O} versus time (Figure 42) with the aid of the calibration curve (Figure 38) using dew point conversions from the steam tables. The feed P_{H_2O} was obtained from the trace just before adsorption and extended through the adsorption time. The removal efficiency for H_2O was then obtained by graphical

LARGE SCALE PARAMETRIC TESTS
HUMIDITY CALCULATIONS DATA CYCLE 70
(RECORDER READING)

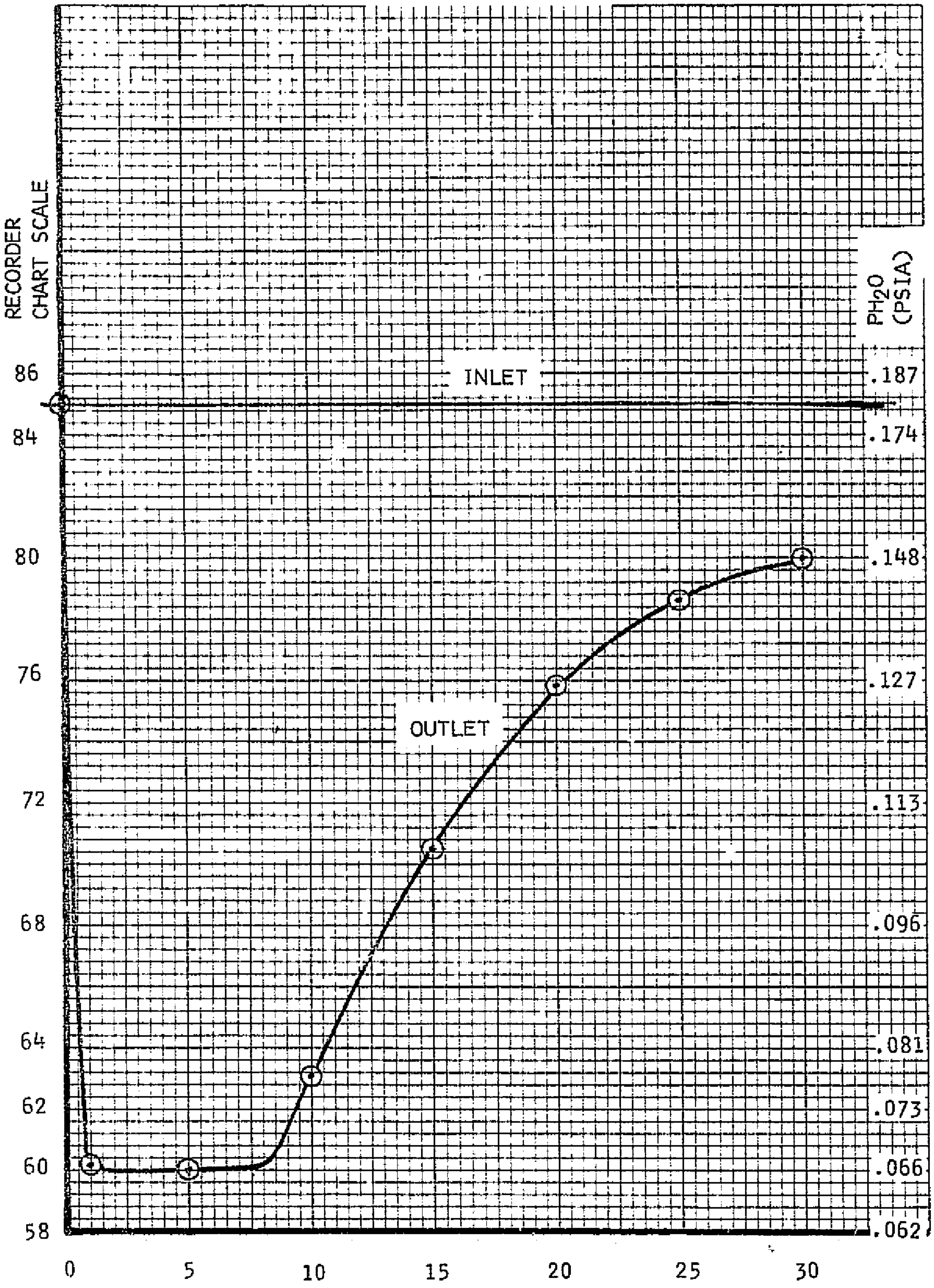


FIGURE 42

LARGE SCALE PARAMETRIC TESTS
HUMIDITY CALCULATIONS - DATA - CYCLE 70

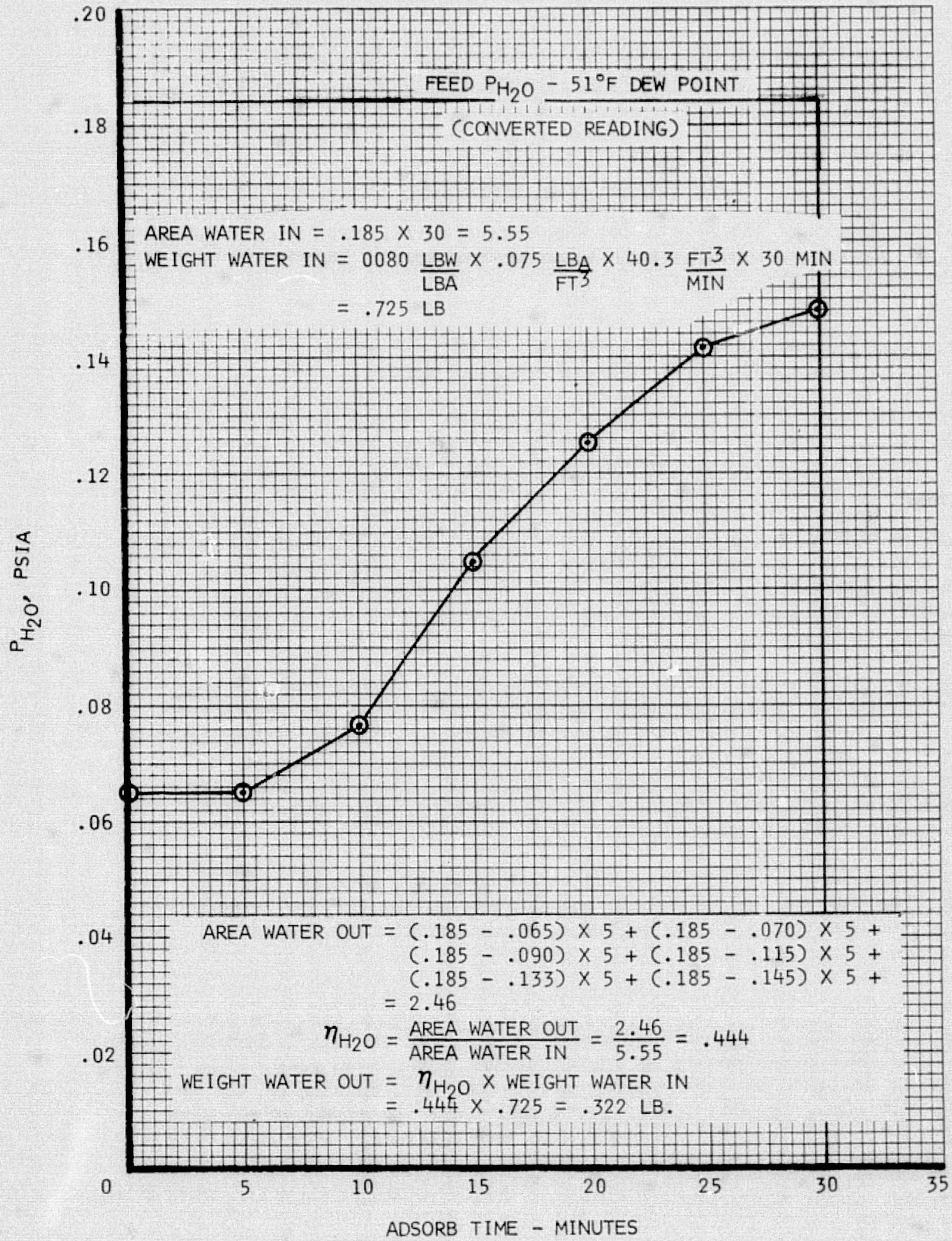


FIGURE 43

integration and the capacity for water vapor then calculated as shown in Figure 43.

Parametric Data Discussion

Appendix F presents log sheets for Run Series I, II, and III. Figures 11 through 17 are plots developed from this parametric data. These plots are discussed below in detail.

Desorption Time, Temperature, and Vacuum

Figures 16 and 17 show the effect on capacity of varying desorption time at CO_2 partial pressures of 5 and 3 mmHg during run series I which employed a 3 in. thick bed of 24-28 mesh HS-C. At 5 mmHg, the shape of the curve is similar but the capacities are about 15% higher. But even the longer desorption times (90-160 min.) leave some of the bed incompletely desorbed, as is shown by the 2.55% CO_2 capacity available after an overnight desorption (1000 min.) at room temperature. Incomplete desorption results from inadequate desorption temperature, too short a desorption time, or too high a desorption pressure -- effects which interact in important ways not investigated in this study.

Desorption temperature.- This parameter is believed most important at the shorter desorption times, although the effect of adsorption temperature masks the effect when adsorption and desorption are at a single temperature (see Figure 12). At 1000 minutes, Figure 16 shows that a desorption temperature of 125°F resulted in only 10% additional capacity, indicating that desorption is reasonably complete after 1000 minutes at normal (80°F) desorption temperature.

Desorption time.- This parameter is very important, because time is required for the CO_2 and H_2O to desorb and diffuse out of the HS-C particle and then for the desorbed gases to work their way through the bed to the simulated space vacuum at either side of the bed.

Desorption pressure.- Figure 17 shows 3 mm CO_2 data in detail including some runs with higher desorption pressures at 45 minutes desorption time. The 3 inch bed was normally desorbed through 3 inch gate valves on each side of the bed. When one was left shut, the desorption performance was decreased, simulating an equal weight of bed 6 inches thick when double end desorbed. Desorbing only through a 3/8 inch I.D. 1/2 inch plastic line (used normally for ullage dump decreased the performance still further.

Decreasing the bed thickness to 1.5 inches with double-end desorption improved capacity about 5% (Run Series II). Decreasing the particle size from 24-28 mesh to 30-40 mesh in the 1.5 inch bed (Run Series III) further improved performance, giving a 15% increase over the base condition, with a 2% CO_2 capacity at 40 minutes desorption.

Even though powerful vacuum pumps were employed, desorption pressure was not instantaneously lowered to the 10-20 microns characteristic for termination of a normal desorption. Figure 44 shows a plot of the desorption pressure traces from a typical run. Performance in an actual spacecraft would be better, provided an adequately large line to space vacuum were provided.

Design for Desorption

The optimal bed configuration will depend on packaging considerations. The best performing bed will be the thinnest bed but a 1-1/2 inch bed is probably heavier overall than a 3 inch bed due to structural requirements.

A thin bed gives a low pressure drop during adsorption, which is also important since the HS-C is a fine material relative to conventional sorbents such as molecular sieve, charcoal, or silica gel. The pressure drop during adsorption is shown in Figure 45 for the bed configurations of each run series. The pressure drop of a 3 inch bed is not prohibitively high, about the same as the usual molecular sieve plus silica gel bed and associated valving.

Inlet CO_2 Concentration

Figure 14 shows the change in CO_2 and water capacity of the HS-C bed with changing CO_2 partial pressure. When the P_{CO_2} is lowered from 3 to 1.5 mmHg the capacity drops about 20%. An increase to 5 mmHg causes a rise of about 10%. A further rise would have little effect because at this P_{CO_2} the rate of adsorption is becoming very much greater than the rate of spontaneous desorption, allowing each reactive site to be occupied almost all the time. Capacity is then independent of adsorption P_{CO_2}, depending only on the number of reaction sites available.

Bed temperature.- Figure 12 shows how little bed temperature affects cyclic performance for CO_2. There is nonetheless an important effect due to temperature on both adsorption and desorption, with adsorption capacity increasing with decreasing temperature while desorption difficulty increases to compensate. Close examination of the performance data when the canister temperature was adjusted downward from 92°F to 67°F (cycle I-58 and 59) shows a capacity of 1.92% (0.17 lbs.), 20% above the normal cyclic capacity

because cycle 59 had a high temperature desorb followed by a low temperature adsorb. Water capacity shows a significant dependence on bed temperature similar to that of the small scale tests, with a reduction of 50% in water capacity when the temperature is increased from 66°F to 92°F.

Inlet Air Temperature.- Air inlet temperature had no effect on performance because the bed temperature is fixed by the coolant temperature which was held constant. (See Figure 11)

Inlet Air Flow.- Increased air flow raised the CO_2 cyclic capacity only slightly because the flow was great enough at each test condition to saturate the bed. Lower flows presumably would show a decreased capacity (dashed line on Figure 15). This effect also shows that gas phase mass transfer does not limit the mass transfer.

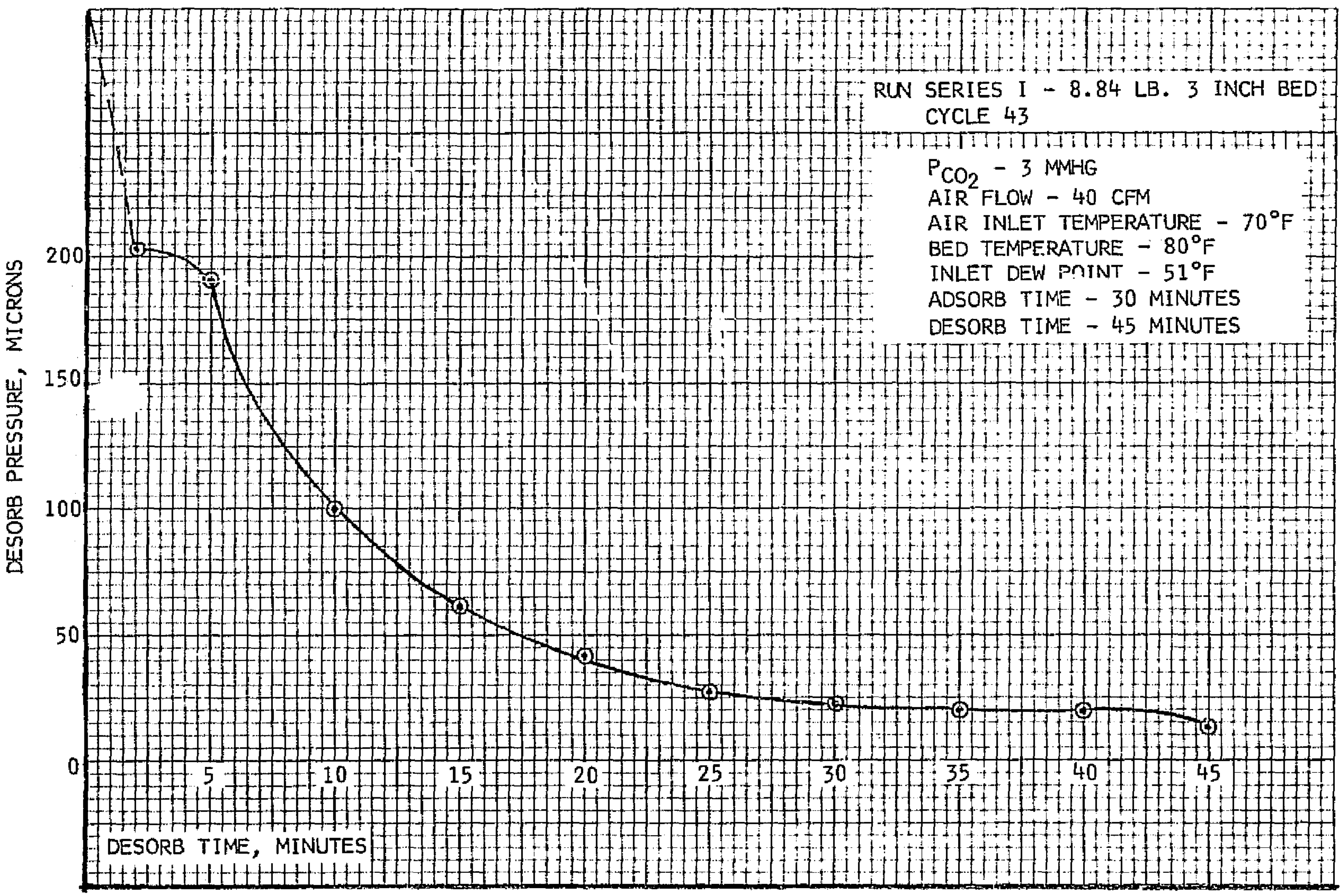
The water in the air flow through the bed was not sufficient to saturate the bed at all conditions. Therefore the more the flow, the greater the cyclic capacity.

Inlet Dew Point.- Figure 13 shows the effect of humidity on water and CO_2 adsorption capacity. The effects are similar to those of the small scale tests (Figure 5). CO_2 capacity is almost unaffected, decreasing slightly at the lower dew points. Water capacity increases rapidly with increasing dew points, and when the inlet flow is high it increases most rapidly.

The water capacity of the bed is limited by the water made available to the bed and by the adsorption time, for the bed is seldom "broken through." The level of the inlet partial pressure driving force is also very important.

Test Data Verification.- CO_2 Capacity: The capacity for CO_2 was determined by direct measurement of the CO_2 added by loss from a weighed gas bottle. The accuracy of the beam balance used was established by trial for small increments (< 2 pounds), using known weights, to be ±.0025 pounds, i.e., a weight could be measured repeatably to the nearest 0.005 lbs. Since operator judgment was involved, all operators were confirmed to be equally accurate with the balance.

Since the CO_2 capacity is measured by weight loss from the CO_2 supply cylinder, a leak from that system or even the test apparatus would have raised the apparent capacity. Such leaks were carefully eliminated prior to data acquisition. Had the problem occurred during operation it would have been quickly noted by the consumption of CO_2 during the desorption cycle when the test canister was by-passed. There was never such consumption and the CO_2 control system remained under closed loop composition control throughout the testing. For an important capacity measurement, as for instance cycles 190-194 of Run Series III, the weight loss was taken over several cycles, in this case 0.555 lbs over six cycles, giving a final capacity of 0.0925



HS-C LARGE SCALE PARAMETRIC TESTS
DESORPTION PRESSURE VS. TIME

FIGURE 44

HS-C LARGE SCALE PARAMETRIC TESTS

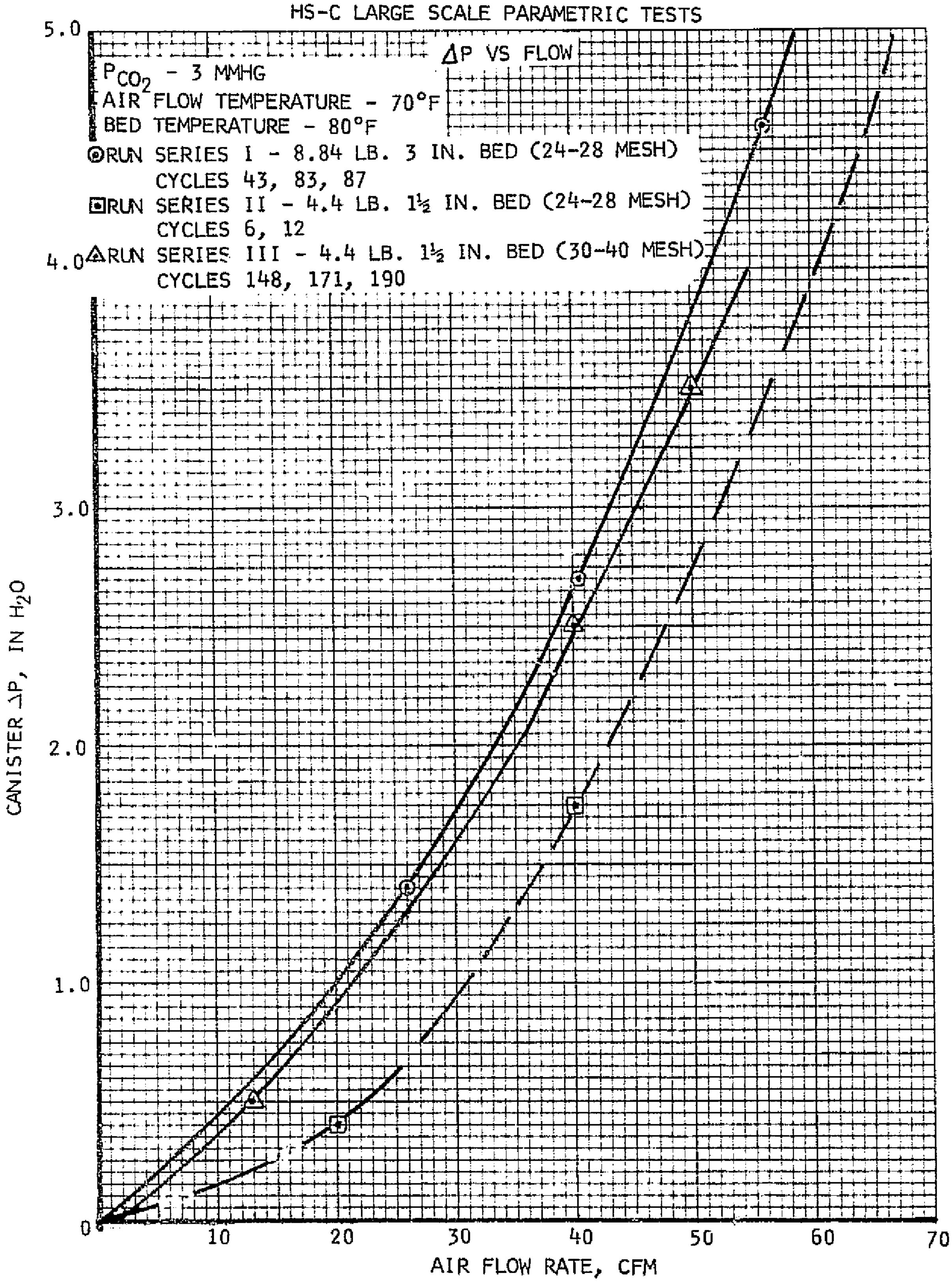


FIGURE 45

±0.0005 lbs/cycle. The results on this series were confirmed by an analysis of the infrared analyzer inlet and outlet traces for cycle 190 using a technique analogous to that used for water capacity (Figures 42 and 43). For cycle 190 the removal efficiency was found to be 4.16%, giving a cyclic capacity of 0.085 lbs. This is within 10% of the 0.0925 lb capacity determined by direct weight, a very satisfactory agreement because the difference between the two infrared analyzers was small for all but the first few minutes of the adsorption cycle.

Water Capacity: Water capacity could not be determined by direct weight because the test apparatus had a large and variable holdup of liquid water. All measurements were therefore made by interpretation of the hygrometer traces as in Figures 42 and 43. Since only the outlet reading was taken (the dew point of the bypassed stream is automatically presented during a canister desorption and is taken as the inlet composition) accuracy requires a constant inlet dew point during the adsorption. The test apparatus provides this, and it was confirmed by recording the actual inlet dew point during a test run.

HS-C SYSTEM DESIGN CONCEPT DEVELOPMENT

The potential for growth in mission duration is evaluated for the regenerable desiccant system. The schematic used for this evaluation was selected on the basis of simplicity and ease of maintenance. It represents a minimum in terms of vehicle interface requirements. The objective of this phase was to develop and trade-off HS-C system design concepts applicable to the Space Shuttle. Experimental data from the large scale tests were combined with the latest shuttle specifications to define system constraints, and describe a realistic trade study.

CONCEPT DESIGN

Figure 47 presents a schematic of that portion of the total Space Shuttle system affected by this study. The schematic shows dual cabin and radiator cooling loops connected by an interface heat exchanger. The heat rejection loop contains electronic equipment cold plates, fuel cell, circulating pumps, a radiator and auxiliary heat sinks. The cabin coolant loop contains electronic cold plates, circulating pumps and associated heat exchangers. Carbon dioxide, humidity and temperature control equipment are shown within the cabin area.

The design requirements and range of conditions considered in this evaluation are shown in Table VI. HS-C parametric data from Run Series I utilized the system sizing is summarized in Figure 46.

The procedures used to minimize the system weight for each candidate concept are shown in Table VII. Included in the optimization were the radiator, coolant pumps and interface heat exchanger, as well as the CO_2, humidity and temperature control and ventilation portions of the subsystem.

At a constant radiator outlet temperature, there is an optimum flow rate. As the heat rejection loop flow is lowered, the radiator size and weight decreases as radiating temperature increases. The cabin heat exchanger weight increases as the heat rejection loop flow decreases because the "log-mean-temperature-difference" in the heat exchanger has decreased. As the radiator outlet temperature is lowered the radiator gets larger, but the cabin heat exchanger gets smaller.

The HS-C sorbent system schematic is shown in Figure 18. Figure 48 illustrates the best competitive system LiOH CO_2 condenser. Design trade

DESIGN REQUIREMENTS

CREW DATA	
Crew Size (men)	2 - 14
Total Metabolic Heat Generation (per man)	540 Btu/hr peak
Sensible Metabolic Heat Generation (per man) (@ 65°F design point)	300 Btu/hr peak
Latent Metabolic Heat Generation (per man)	240 Btu/hr peak
Carbon Dioxide Production Rate	
average	2.2 lb/man-day
maximum	3.8 lb/man-day
PRESSURIZED COMPARTMENT DATA	
Total Pressure	14.7 psia
Oxygen Partial Pressure	3.1 psia
Atmosphere Diluent Gas	Nitrogen
Carbon Dioxide Partial Pressure Levels	
Nominal	5.0 mm Hg
Maximum normal	7.6 mm Hg
Maximum with single failure	10.0 mm Hg
Maximum emergency (2 hour duration)	15.0 mm Hg
Cabin Temperature (Design Point 65°F)	65° to 75°F
Cabin Humidity (dew point temp.)	40° to 57°F
Design point -65°F cabin temperature (12°F less than dry bulb temp.)	53°F maximum
Cabin Volume (4 men)	1000 ft^3
Minimum Ventilation Flow Rate (see ventilation section)	400 cfm
Trace Contaminant Control Penalty (charcoal only)	0.167 lb/man-day
VEHICLE DATA	
Cabin Wall Heat Load (Except for reentry)	1700 Btu/hr
Air Cooled Electronics Heat Load (less EC/LSS load)	3400 Btu/hr
Cold Plate Cooled Electronics Heat Load (cabin)	8800 Btu/hr
Fuel Cell Heat Load	30,000 Btu/hr
Power Penalty	
Fixed Weight	286 lb/kW
Expendables	1.96 lb/kW-hr
Coolant	
Cabin cooling loop	Water
Radiator cooling loop	Freon-21

TABLE VI

Radiator Weight Penalty (WT)

WT = $A \times W \times C_p \times (B-C) \sim$ lbs.

A = $F \times T_s/K \sim$ lbs-hr-°R/Btu

Ts = Equilibrium surface temp ~ °R

K = Radiator Influx ~ Btu/hr-ft^2

W = Radiator coolant flow rate ~ lbs/hr

Cp ~ Radiator coolant flow specific heat ~ Btu/lb-°R

$$B = 1/4 \ln \left[\frac{\left(\frac{TRO}{T_s} + 1\right)\left(\frac{TRI}{T_s} - 1\right)}{\left(\frac{TRO}{T_s} - 1\right)\left(\frac{TRI}{T_s} + 1\right)} \right]$$

$$C = 1/2 \left[\tan^{-1}\left(\frac{TRI}{T_s}\right) - \tan^{-1}\left(\frac{TRO}{T_s}\right) \right]$$

TRI ~ Radiator Inlet Temp ~ °R

TRO ~ Radiator Outlet Temp ~ °R

F = lbs/ft^2/Fin efficiency ~ lbs/ft^2

For Nominal Conditions

A = 7.05 lbs-hr-°R/Btu

T_s = 490°R

TABLE VI
(CONTINUED)

OPTIMIZATION PROCEDURE

1. Assume heat rejection loop flow rate. (freon)
2. Assume radiator outlet temperature.
3. Calculate interface heat exchanger heat rejection loop inlet temperature (size sublimator, if required).
4. Assume interface heat exchanger water outlet temperature.
5. Size/optimize CO_2 and water removal components.
6. Optimize cabin heat exchanger to find optimum air flow and outlet air temperature.
7. Calculate water loop temperatures and pump power and weight.
8. Size interface heat exchanger.
9. Calculate heat rejection loop temperatures and pump power and weight.
10. Size radiator (use cryogenics if area exceeds 900 ft^2).
11. Calculate total system equivalent weight.
12. Repeat steps 4 through 11 until optimum temperature is found.
13. Repeat steps 3 through 12 until optimum radiator outlet temperature is found.
14. Repeat steps 1 through 13 until optimum flow rate is found.

TABLE VII

HS-C LARGE SCALE PARAMETRIC TESTS CYCLIC CAPACITY

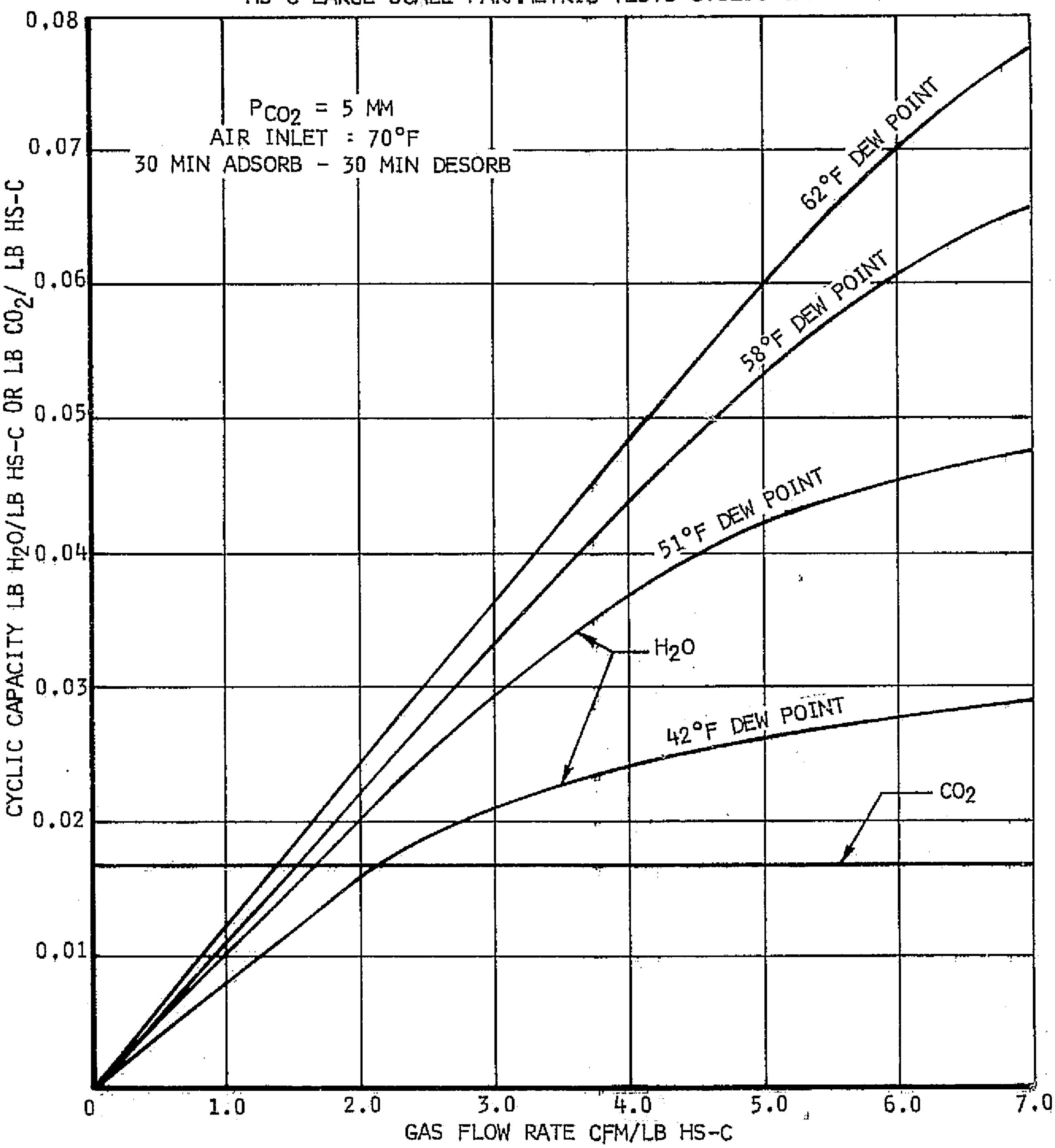


FIGURE 46

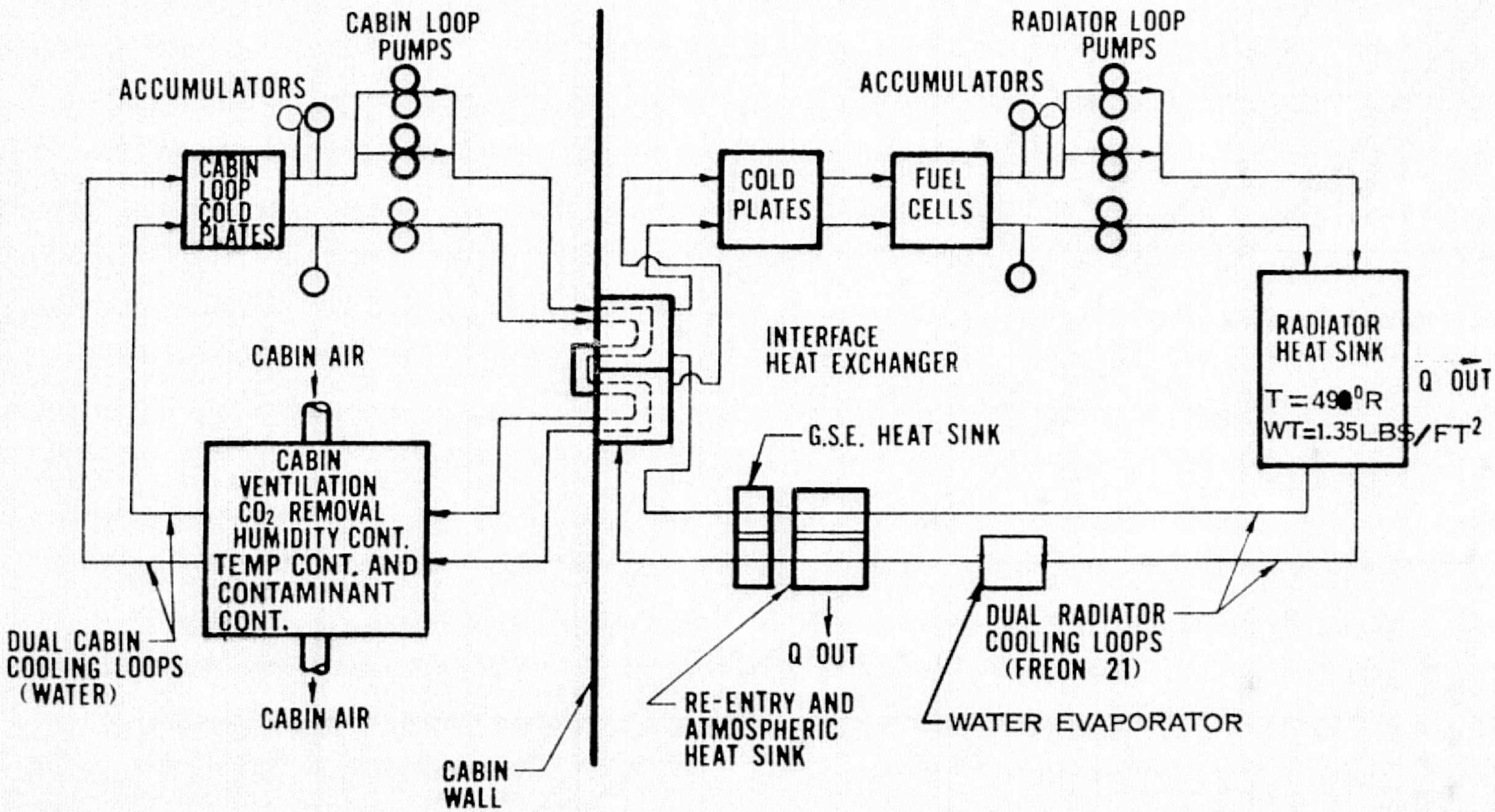


FIGURE 47

COOLANT LOOP SCHEMATIC

SCHEMATIC OF COMPETITIVE SYSTEM LiOH CONDENSER
USED FOR TRADE STUDY

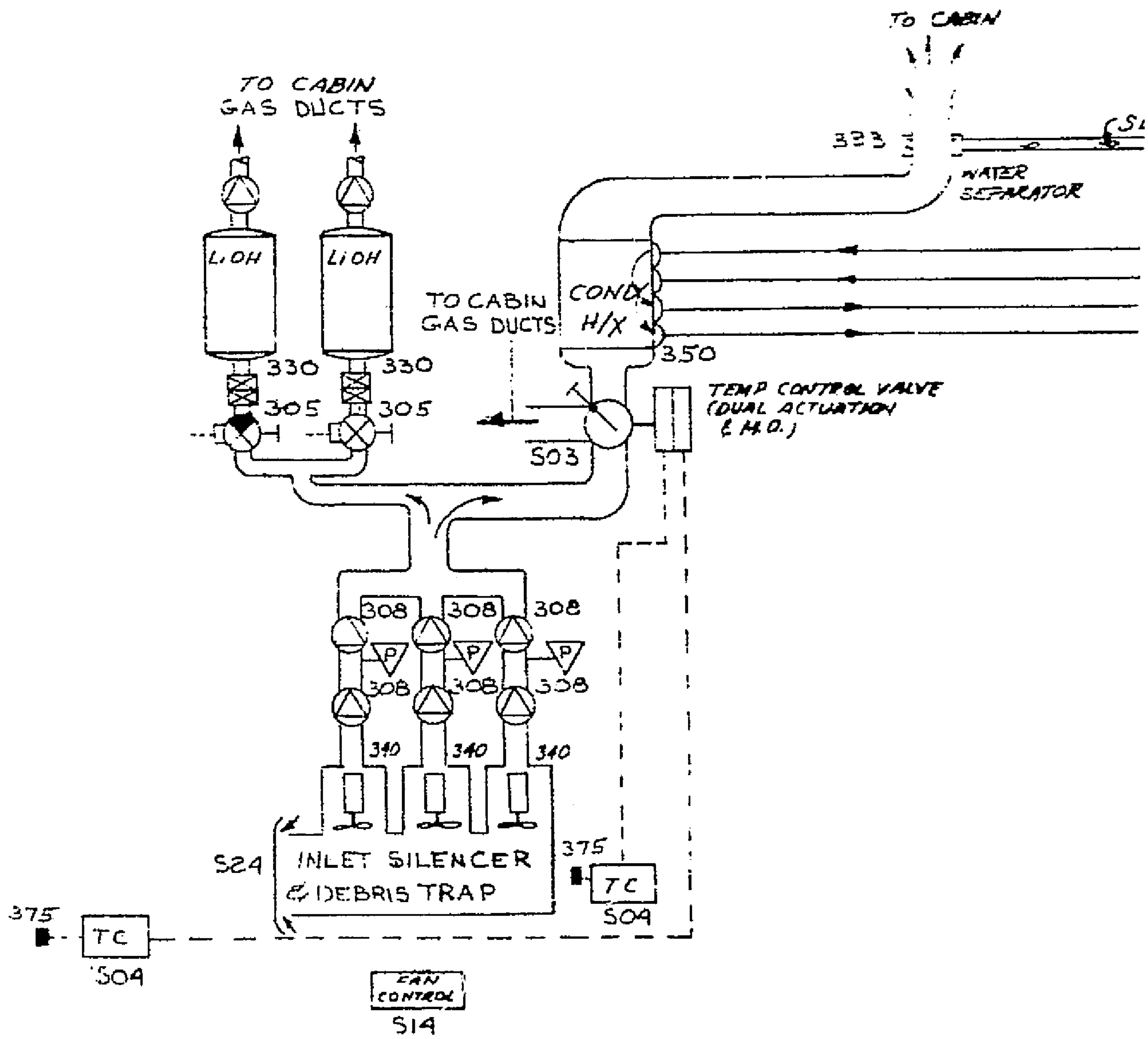


FIGURE 48

results are shown in Figure 19 and 20. System total equivalent weight, is plotted as functions of crew size and a two-day emergency period is included in addition to the mission length. Since the water and CO_2 removal capability depends on the size of the HS-C bed the CO_2 and water generation rates determine the bed size. If the latent (water) load in the cabin is high, the large HS-C bed needed to control water will easily handle the CO_2 requirement and the P_{CO_2} will fall below the nominal level. Conversely when CO_2 sizes the bed the cabin P_{H_2O} will fall below nominal and possible out of specification. Fortunately this situation can be avoided by lowering air flow through the canister (See Figure 46).

For the current shuttle requirements, computer results show that water removal alone determines the HS-C system size. The LiOH condenser subsystem, however, is sized by CO_2 removal. For a six-man seven-day, two-day emergency mission, the total equivalent weight for the HS-C subsystem is 1890.7 pounds. The equivalent weight for a LiOH condenser subsystem is 2091.4 pounds. The HS-C subsystem maintains a lower dew point, requires less flow rate, and utilizes a smaller radiator heat sink.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

CR-115568
SVHSER-6040

APPENDIX A

PLAN OF TEST & TEST DATA

HS-C STRUCTURAL TESTS

PRECEDING PAGE BLANK NOT FILMED

HS F-927 6/66

TEST NO. ________

HAMILTON STANDARD

CR-115568
SVHSER-6040

PLAN OF TEST

JOB: ________ PLAN PREPARED BY: H. Kolnsberg

PROJECT & ORDER: HS-C Structural Tests APPROVED BY: ________

INSTRUCTION: ________ TEST ENGINEER: ________

TIME PERIOD: ________ TO ________

1. WHAT IS ITEM BEING TESTED?
2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?
3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.
4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.
5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.
6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1.0 Description of Test Item

The test item is virgin HS-C CO_2 adsorbing desiccant.

2.0 Test Objective

The objective of these tests is to demonstrate that the material will not be significantly structurally damaged or operationally degraded under space flight conditions. The vibration levels used are those for lunar launch and boost used in testing LM hardware.

3.0 Description of Test Set-up

3.1 Test Facility

The vibration test described herein will be conducted in the Hamilton Standard Vibration facility, Rig number 26 . All other tests will be conducted in the Hamilton Standard Advanced Engineering Laboratory.

3.2 Test Set-up

The adsorption test set up will be as shown in Figure 1.
The pressure drop test set-up will be as shown in Figure 2.
The vibration test set-up will be as shown in Figure 3.

3.3 Test Sequence

In order to minimize the amount of material required for testing, the following sequence of testing will be followed:

Configuration	-	pre-vibration sample (1 ml)
Apparent density	-	pre-vibration sample (100 ml)
*Adsorption	-	pre-vibration sample (5 ml)
Pressure Drop	-	pre-vibration canister (6 lb)
Vibration test	-	canister
Pressure drop	-	post-vibration canister
*Adsorption	-	post-virbation sample (5 ml)
Confuguration	-	post-vibration sample (1 ml)
Apparent density	-	post-vibration sample (100 ml)

* Adsorption tests may be run simultaneously.

4.0 Test Procedures

4.1 Configuration Test

Extract a 1 ml (or a minimum of 100 beads) sample at random from the test volume.

Spread sample to single bead thickness and examine under at least 10X magnification.

Record number and percent of beads with irregular surfaces. Note type (raised bumps, chips, cracks) of irregularities.

4.2 Apparent Density - (per ASTM C136-46)

Extract a sample of approximately 50 gm from the test volume and weigh to the nearest 0.1 gm. Record weight. Transfer sample to a clean, dry 500 ml glass graduated cylinder. Incline and rotate the cylinder until the sample flows freely. Level the sample in the cylinder by tipping the vertically held cylinder back and forth without tapping or jarring. Determine and record sample volume in ml.

The apparent density is equal to the sample weight divided by the sample volume.

4.3 Adsorption

Extract a sample of approximately 5 ml from the test volume and install in the laboratory test rig. Set the following test conditions:

P_{CO_2} - 3 mm Hg
Air flow - 500 ml/min
P_{total} - 28 in Hg
Air inlet dew point - 52°F
Bed temperature - 75°F
$\frac{1}{2}$ Cycle time - 45 min
P_{desorb} - 50 micron max.

4.3 Adsorption (continued)

Run test for three adsorb-desorb cycles. Report capacity data on sorbent evaluator calculation sheet.

4.4 Pressure drop

Install approximately 6 pounds of the sample volume in an SV742060 (IM 122) cartridge. Fill cartridge to within 1/8 inch of the cartridge cover cushion disc. Do not tap or jar cartridge during filling.

Install filled cartridge in SV748770 (IM 110) canister and install cartridge in test rig as shown in Figure 2.

Adjust flow of nitrogen to 25 cfm or to a pressure drop of 5 inches H_2O across the canister, whichever occurs first as the nitrogen flow is increased. Record nitrogen flow and canister P. Repeat fan 20 cfm (or 4 inches H_2O ΔP) and 30 cfm (or 6 inches H_2O ΔP).

4.5 Vibration Test

Install the HS-C loaded cartridge (Paragraph 4.4) in the test structure as shown in Figure 3.

Vibrate the test item such that the vibration inputs at either control accelerometer location are at the following levels:

X-axis random vibration - 1 minute 0 12.4 g RMS

20 - 265 Hz	.005 g^2/Hz
265 - 750 Hz	+12 db/octave
750 - 850 Hz	.3 g^2/Hz
850 - 200 Hz	-12 db/octave

Sinusoidal vibration - 3 octave/min

5 - 14 Hz	.2 in D.A.
14 - 100 Hz	2G
100 - 14 Hz	2G
14 - 5 Hz	.2 in D.A.

Filter the control accelerometer during each test. Filter other accelerometer outputs during playback. Plot control and response data to slow filtered g's versus frequency for sine data and g^2/Hz versus frequency for random data.

5.0 Special Instructions

Not Applicable

6.0 Data Presentation

Tabulate the test results to show % of beads with irregular surfaces, apparent density in gm/ml, CO_2 adsorption in % by weight and gms/liter, and pressure

6.0 Data Presentation (continued)

drop across the canister in in. H_2O for each of three gas flow rates for samples taken before and after the vibration test.

Figure 1

Lab Rig Schematic (Adsorption Test)

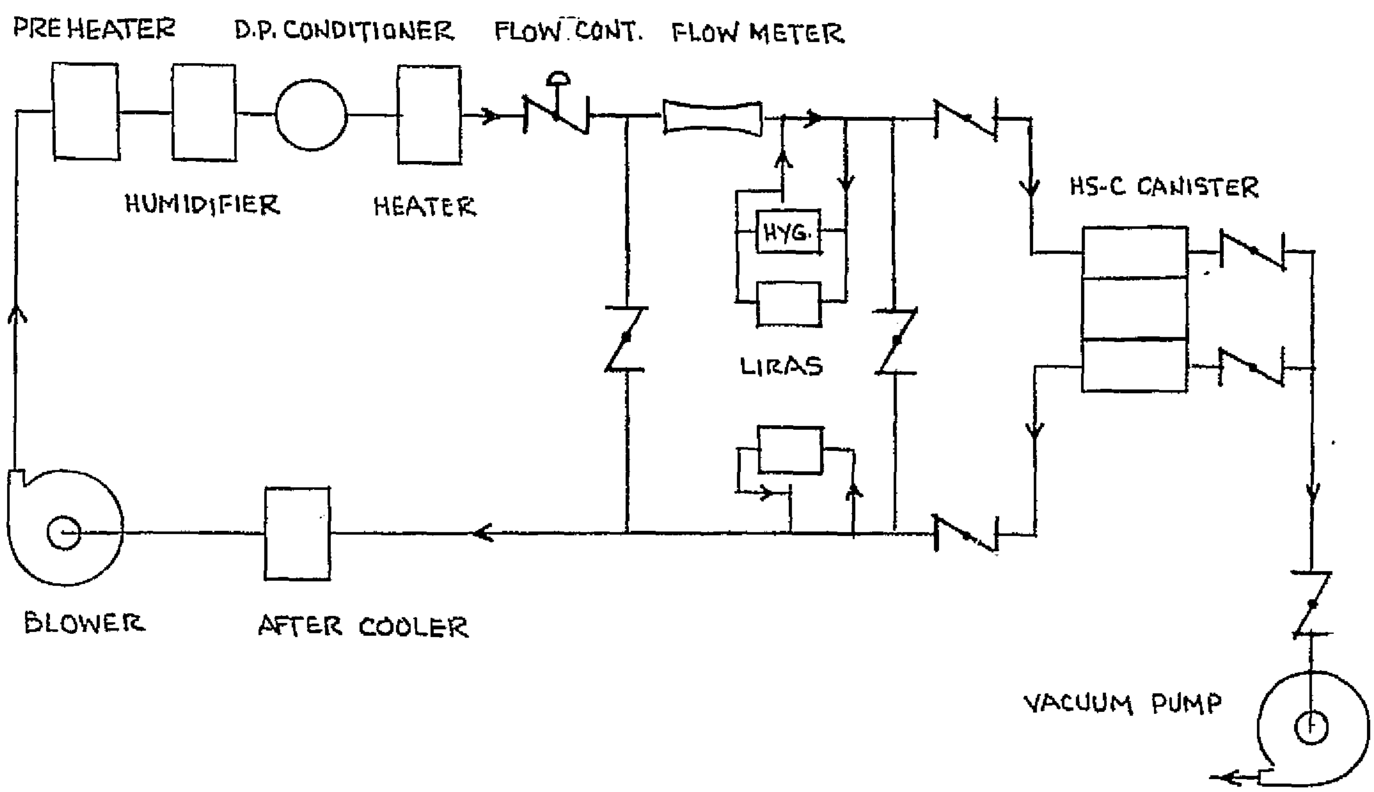


Figure 2

Pressure Drop Test Set Up

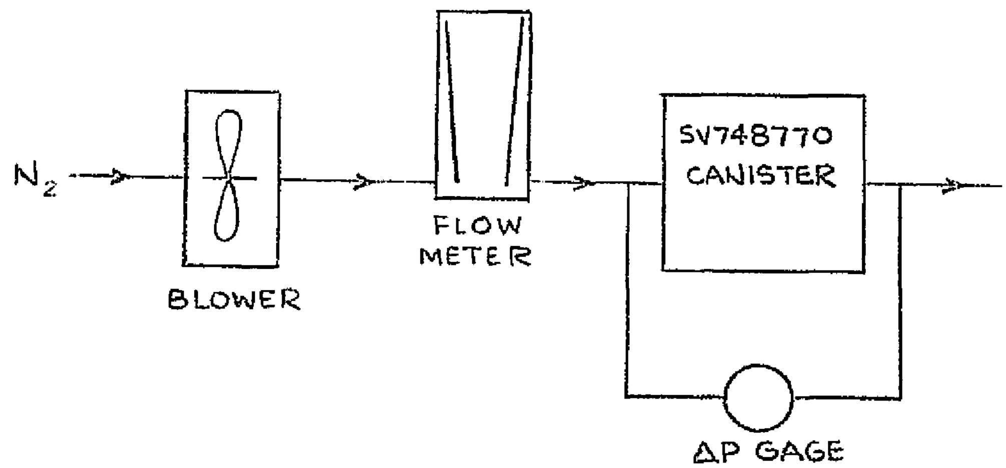
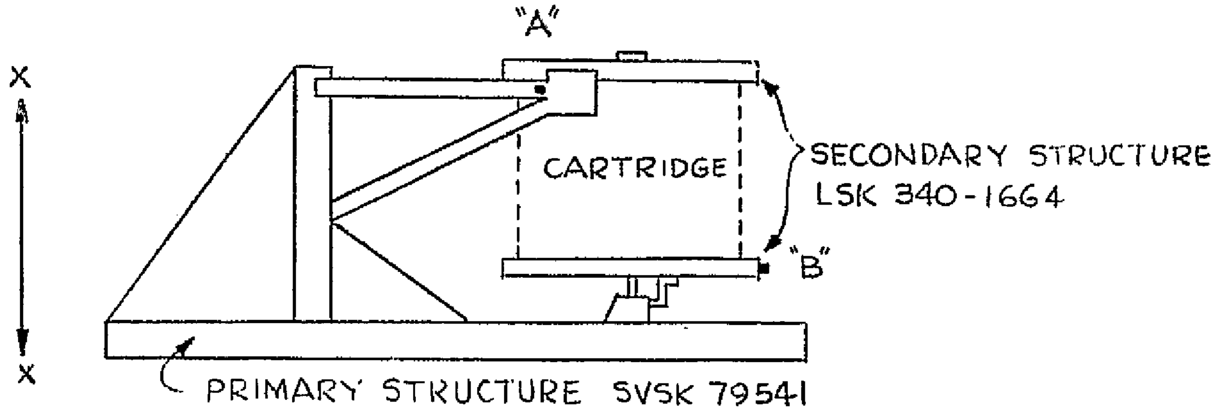


Figure 3

Vibration Test Set Up



When location "A" is used as the control accelerometer, location "B" shall be used for response data and vice versa.

Cartridge Installation Procedure

1. Back off adjusting screws to clear canister.

2. Position .014 shim between screws and canister.

3. Adjust each screw until shim is snug between screw and canister.

4. Back off screws only enough to remove shims. Turn each screw clockwise 180° $+0^{\circ}$, -15°.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: HS-C CANISTER PRESSURE DROP
TEST ENGINEER: H. KOLNSBERG
NAME OF RIG: 88
PROJECT & ENG. ORDER NO.

SHEET 1 OF 1 DATE 11/22/71
TEST PLAN NO.
MODEL NO.
PART NO.
SERIAL NO.
OPERATORS

CR-115568
SVHSER-6040

DATE	TIME	VENTURI INLET	VENTURI ΔP	ΔP/P	AIR FLOW	CAN ΔP	
—	—	PSIA	IN. H_2O	—	CFM	IN H_2O	
11/22	1422	14.92	11.7	.028	30.5	1.45	BEFORE VIBRATION TEST
	1455	14.82	8.2	.0195	25.5	1.05	
	1508	14.72	5.25	.0128	20.6	0.70	
	1600	14.94	11.4	.0273	30.1	1.40	
	1605	14.83	8.1	.0192	25.1	1.00	
	1610	14.74	5.4	.0129	20.7	0.7	
11/24	0825	15.14	4.8	.0119	20.0	0.65	AFTER VIBRATION TEST
	0830	15.23	7.6	.0182	24.5	0.95	
	0835	15.36	11.4	.0273	30.1	1.40	
	0840	15.40	12.7	.030	31.5	1.52	
	0845	15.37	11.8	.0285	30.7	1.44	
	0850	15.20	6.2	.0149	22.1	0.80	
	0855	15.12	4.7	.0113	19.5	0.63	

REMARKS:

3387

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

A-8

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

HS-C CONFIG ATION & DENSITY

TEST ENGINEER H. KOLNSBERG

NAME OF RIG ———

PROJECT & ENG. ORDER NO.

SHEET 1 OF 1 DATE 1-24-71

TEST PLAN NO

MODEL NO.

PART NO.

SERIAL NO.

OPERATORS

CR-115568
SVHSER-6040

CONFIGURATION - 20X MAGNIFICATION

BEADS IN SAMPLE	IRREGULAR BEADS	% IRREGULAR	
~370	5	1.35	- PRE-VIBRATION SAMPLE - ALL IRREGULAR BEADS HEMISPHERICAL
~380	4	1.05	- POST-VIBRATION SAMPLE - ALL IRREGULAR BEADS HEMISPHERICAL

APPARENT DENSITY

SAMPLE WEIGHT gms	SAMPLE VOLUME ML	A.D. gm/ml	
50.6	126	.402	- PRE-VIBRATION SAMPLE
51.5	128	.402	- POST-VIBRATION SAMPLE

REMARKS:

3386

Hamilton Standard

SVHSER-6040

Memo File Code SSD-CO2-1189

Memorandum to: H. KOLNSBERG

Page 1 of

Program CO_2 DESICCANT

Test Item(s) HS-C CO_2 ABSORBING DESICCANT

Date of Test 11/23/71

Serial No.(s)

Name of Test DVT VIBRATION

Specification TEST PLAN

Subject:

TYPE HS-C CO_2 ABSORBING DESICCANT WAS LOADED IN A LM 122 DVT CARTRIDGE AND VIBRATED ON FIXTURE SVSK 79541. ONLY ONE AXIS, (X) VERTICAL, WAS TO BE TESTED WITH CONTROL ON THE SECONDARY FIXTURE'S TOP BRACKET.

THERE WAS NO UNUSUAL HAPPENING AND NO GROSS DUSTING.

INSTRUMENTATION INCLUDED ACCELEROMETERS AT CONTROL, CROSSAXES NEAR CONTROL (ON TOP BRACKET) AND PRIMARY DIRECTION ON THE BOTTOM FIXTURE CUP.

THIS REPORT INCLUDES CONTROL AND RESPONSE CURVES FROM ONE SINE AND ONE RANDOM TEST.

Test Engineer T. GEIB

Signature T. Geib

Date of Report 12/15/71

Approved [signature] Date Dec 15, 1971

OPERATOR LOG #1290, TAPE LOGS, AND DATA REDUCTION LOGS.

THE MAGNETIC TAPE DATA WILL BE ERASED IN 90 DAYS UNLESS A SPECIFIC REQUEST IS MADE TO THE UNDERSIGNED.

SVHSER-6040

Memo No. SSD-CO2-1189

Page No. 1 of 1

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

Memorandum to: Structures Group

Date of Test: 11/23/71

Date of Memo: 12/8/71

Program: CO_2 DESICCANT

Type of Test: DVT VIB.

Test Item(s): H S C CO_2 ABSORBING DESICCANT

S/N:

Remarks:

REDUCED DATA FROM (1) SINE & (1) RANDOM
— (4) CURVES EACH
OPERATOR LOG 1290
TAPE LOGS & D.R. LOGS

TESTED IN LM 122 CARTRIDGE ON SVSK 79541
Fixture IN X AXIS ONLY (VERTICAL)

Operational Test Engineer

Date

Received - Date

TER No.

Return[redacted] to T. GEIB

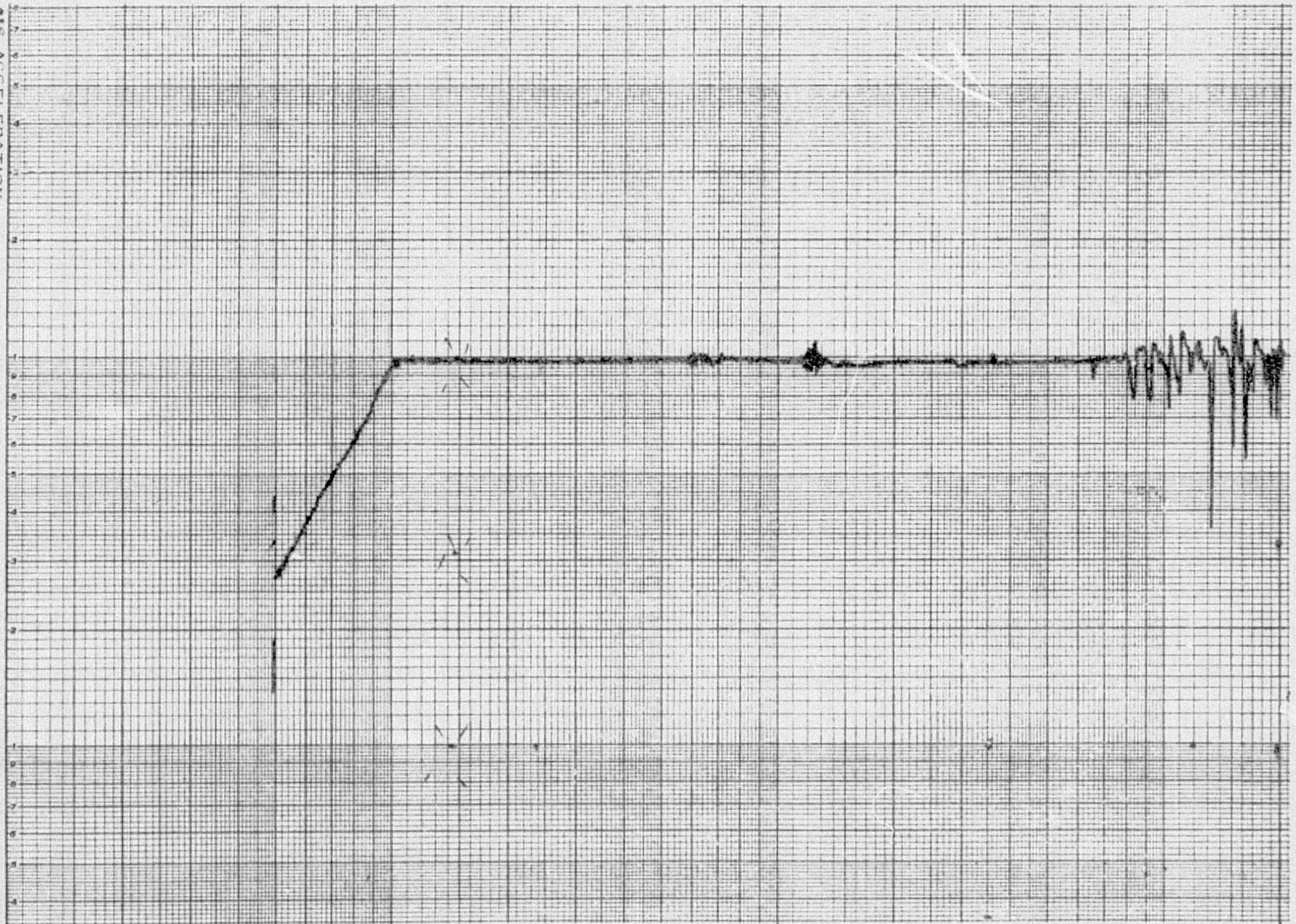
Action Taken - Date

Hamilton Standard U A® DIVISION OF UNITED AIRCRAFT CORPORATION HSF-1633.1 2/69

SINE VIBRATION TEST

A-12

RIG	OPERATOR	WITNESS	WITNESS		TEST NO.
# 26	P. Jordan	—	—		2
TEST ENGINEER	CHECKED BY	PROJECT		DATE	TIME
T. Geib	T.G	CO_2 DESICCANT		11-23-71	1355



PAGE NO.

INPUT LEVEL: ±1.0 g	EXCIT. AXIS: x
ACCEL S/N: PB34	SENSING AXIS: x
ACCEL SENSITIVITY: — MV RMS / GP; 2.333 COL / GP	
FILTER: 10 100 200 HZ B.W.	
FILTER CROSSOVER: @ 70 700 HZ	
SWEEP RATE: 3.0 OCT/MIN	
TAPE REEL NO.: 012255	☑ LIVE ☐ FROM TAPE
COMPR. SPEED: Var DB/SEC.	
CHG.@ ~ HZ TO ~ DB/SEC.	
CHG.@ ~ HZ TO DB/SEC.	
NON OPERATING	☑ CONTROL
TEMP. 74 °F	☐ RESPONSE
LOCATION: "A"	
SPECIAL CONDITIONS	

REPORT NO. CR-115568 SVHSER-6040

FREQ. RANGE & DIRECTION	ITEM	CODE	SERIAL NO.	SPEC.	PARA.	AMEND.
5-2K HZ	H.S-C-CO2	—	—	Plan of Test	—	—

ACTION SHEET NO.	ATA NO.	TYPE OF TEST	NAME OF TEST
—	—	DVT	Sine Scan

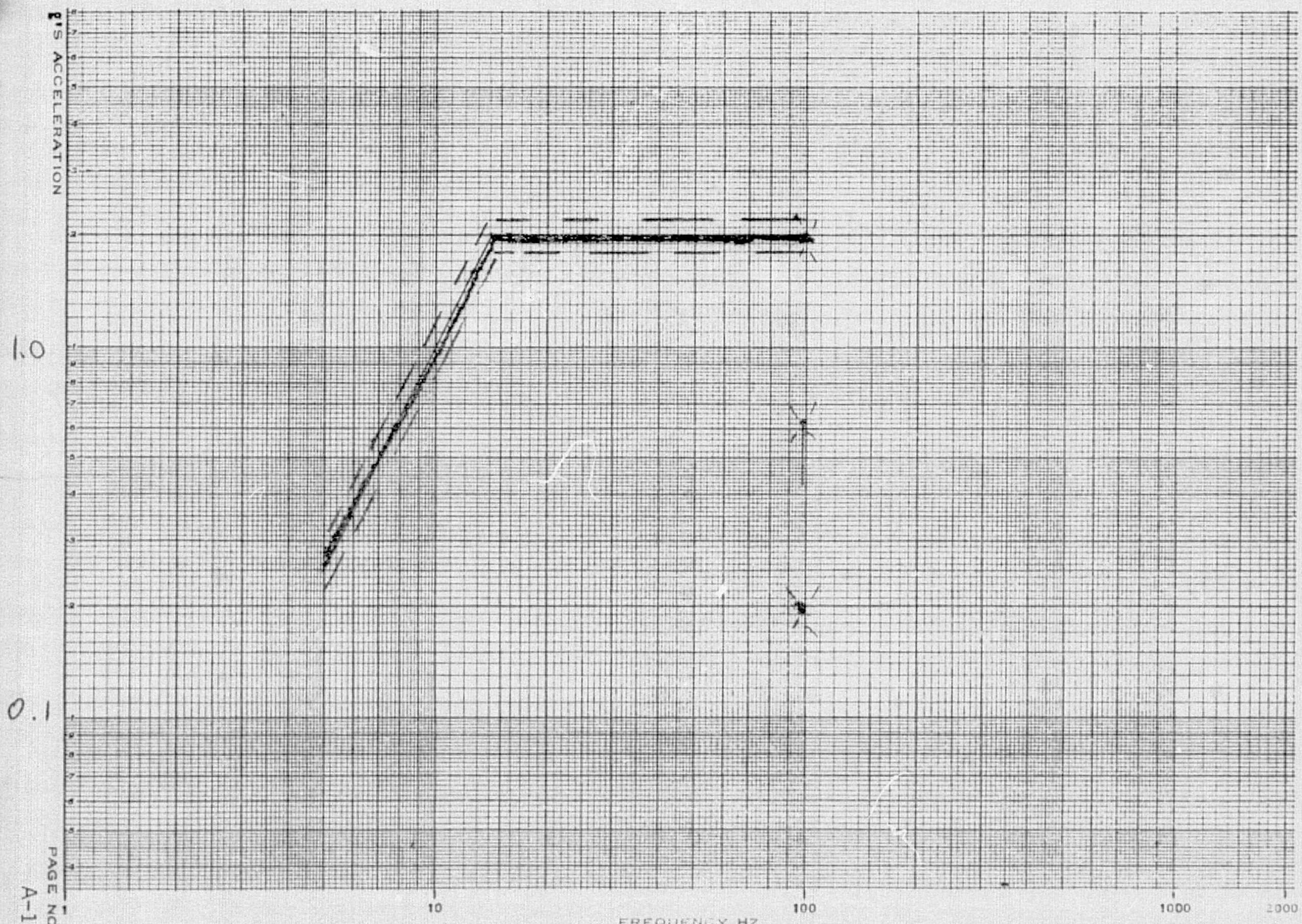
Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION

SINE VIBRATION TEST

HSF-1633.1 2/69

RIG	OPERATOR	WITNESS	WITNESS	TEST NO.
# 26	P. Jodoin	—	—	4

TEST ENGINEER	CHECKED BY	PROJECT	DATE	TIME
T. Geib	T G.	CO_2 DESICCANT	11-23-71	1440



INPUT LEVEL: ± 2.0 g	EXCIT. AXIS: x
ACCEL S/N: PB34	SENSING AXIS: x
ACCEL SENSITIVITY: — MV RMS / GP; 2.333 COL / GP	
FILTER: 16, 100 [redacted] HZ B.W.	
FILTER CROSSOVER: @ 70 [redacted] HZ	
SWEEP RATE: 3.0 OCT/MIN	
TAPEREEL NO.: 012255	☑ LIVE ☐ FROM TAPE
COMPR. SPEED: Var. DB/SEC.	
CHG. @ — HZ TO DB/SEC.	
CHG. @ — HZ TO DB/SEC.	
NON OPERATING	☑ CONTROL
TEMP. 74 °F	☐ RESPONSE
LOCATION: "A"	
SPECIAL CONDITIONS:	

REPORT NO. CR-115568 SVHSER-6040

FREQ. RANGE & DIRECTION	ITEM	CODE	SERIAL NO.	SPEC.	PARA.	AMEND.
5-100-5 HZ	HS-C CO_2 DESIC	—	—	TEST PLAN	—	—

ACTION SHEET NO.	ATA NO.	TYPE OF TEST	NAME OF TEST
—	—	DVT	Sine Run

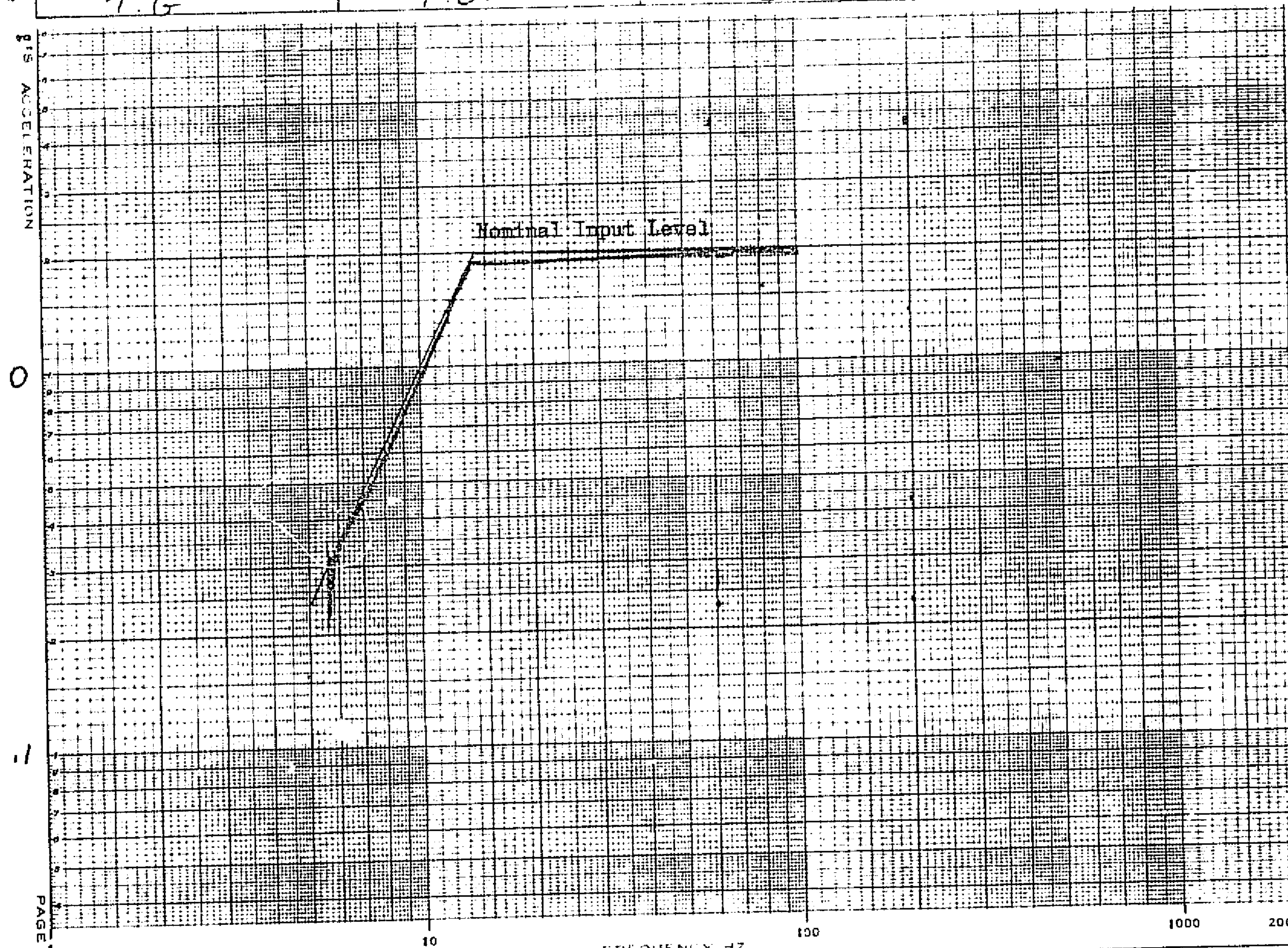
Hamilton Standard

SINE VIBRATION TEST

HSF 1633 A

RIG	OPERATOR	PLOTTED BY	TRACE NO.	TEST NO.
26	P. J.	P. J		4

TEST ENGINEER	CHECKED BY	PROJECT	DATE	TIME
T. G	T. G	CO_2 DESICCANT	11-23-71	1440



INPUT LEVEL ± 2.0 g	EXCIT. AXIS X
ACCEL S/N PB34	SENSING AXIS X
ACCEL SENSITIVITY — MV RMS / GP; 2.333 COL / GP	
FILTER 10 HZ B.W.	
FILTER CROSSOVER — @ HZ	
TAPEREEL NO. 012255	SWEEP RATE 3.0 OCT/MIN
COMPR. SPEED VAR DB/SEC	
CHG@ — HZ TO — DB/SEC	
CHG@ — HZ TO — DB/SEC	
NON-OPERATING	☑ CONTROL
TEMP. 74 °F	☐ RESPONSE
LOCATION A TOP BRACKET	
SPECIAL CONDITIONS	

REPORT NO.
CR-115568
SVHSER-6040

FREQ. RANGE & DIRECTION	ITEM	CODE	SERIAL NO.	TYPE OF TEST
5-100-5 HZ	HS-C DESIC	—	—	DVT
SPECIFICATION	PARA.	AMEND.	PHASE	NAME OF TEST
TEST PLAN	—	—	—	—

PAGE NO.

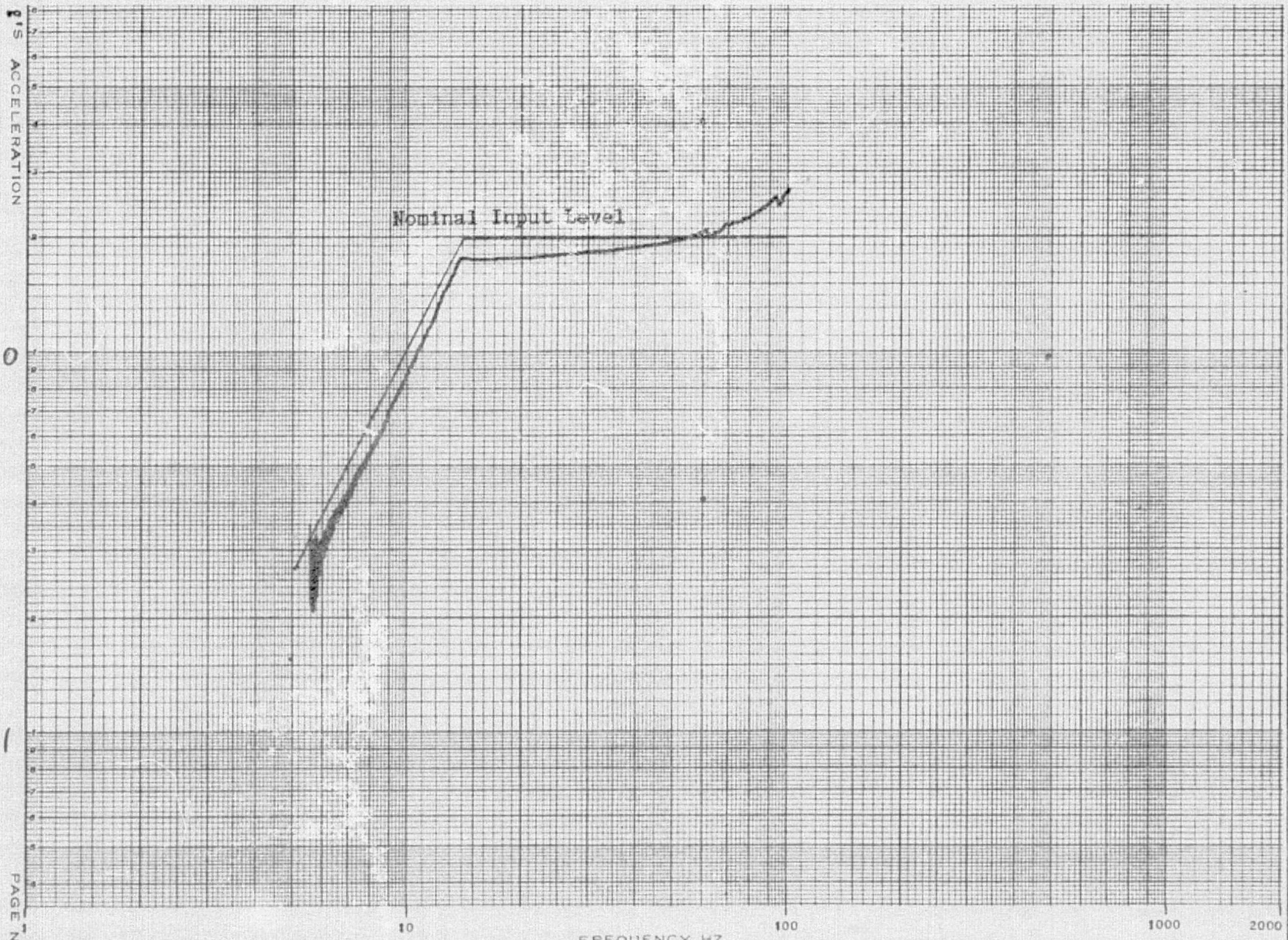
HSF 1633 A 2/69

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION

SINE VIBRATION TEST

RIG	OPERATOR	PLOTTED BY	TRACE NO.	TEST NO.
26	P. J.	P. J.	—	4

TEST ENGINEER	CHECKED BY	PROJECT	DATE	TIME
T. G.	T. G.	CO_2 DESICCANT	11-23-71	1440



INPUT LEVEL: ± 2.0 g	EXCIT. AXIS: X
ACCEL S/N: PB36	SENSING AXIS: X
ACCEL SENSITIVITY: — MV RMS/GP; 2.489 COL/GP	
FILTER: 10 HZ B.W.	
FILTER CROSSOVER @ — HZ	
TAPE REEL NO.: 012263	SWEEP RATE: 3.0 OCT/MIN
COMPR. SPEED: VAR. DB/SEC	
CHG@ — HZ TO — DB/SEC	
CHG@ — HZ TO — DB/SEC	
NON-OPERATING	☐ CONTROL
TEMP. 74 °F	☑ RESPONSE
LOCATION: "B" BOTTOM BRACKET	
SPECIAL CONDITIONS	

FREQ. RANGE & DIRECTION	ITEM	CODE	SERIAL NO.	TYPE OF TEST
5-100-5 HZ	HS-C DESIC	—	—	DVT

SPECIFICATION	PARA.	AMEND.	PHASE	NAME OF TEST
TEST PLAN	—	—	—	—

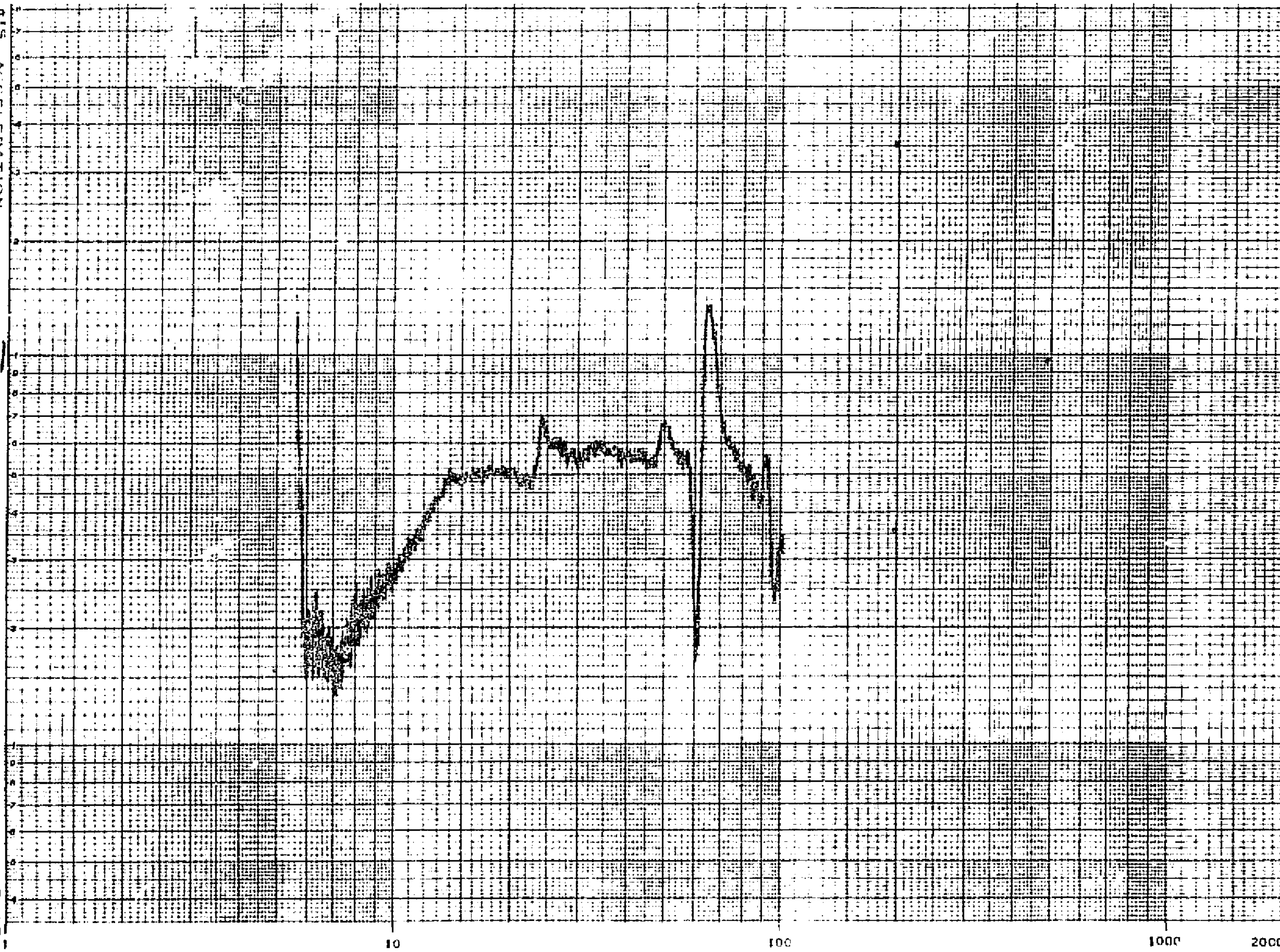
REPORT NO. CR-115568 SVHSER-6040

Hamilton Standard

SINE VIBRATION TEST

RIG	OPERATOR		TRACE NO.	TEST NO.
26	P.J.	P.J.		4

TEST ENGINEER	CHECKED BY	PROJECT	DATE	TIME
T.G.	T.G.	CO_2 DESICCANT	11-23-71	1440



INPUT LEVEL ± 2.0 g	EXCIT. AXIS X
ACCEL S/N NB82	SENSING AXIS B
ACCEL SENSITIVITY — MV RMS / GP; 2.848 COL / GP	
FILTER 10 HZ B.W.	
FILTER CROSSOVER @ HZ	
TAPE REEL NO. 012255	SWEEP RATE 3.0 OCT/MIN
COMPR. SPEED VAR DB/SEC	
CHG@ — HZ TO — DB/SEC	
CHG@ — HZ TO DB/SEC	
NON-OPERATING	☐ CONTROL
TEMP. 74 °F	☑ RESPONSE
LOCATION B (CROSSAXIS) TOP BRACKET	
SPECIAL CONDITIONS	

REPORT NO. CR-115568 SVHSER-6040

FREQ. RANGE & DIRECTION	ITEM	CODE	SERIAL NO.	TYPE OF TEST
5-100-5 HZ	HS-C DESC.			DVT
SPECIFICATION	PARA.	AMEND.	PHASE	NAME OF TEST
TEST PLAN	—	—	—	—

PAGE NO.

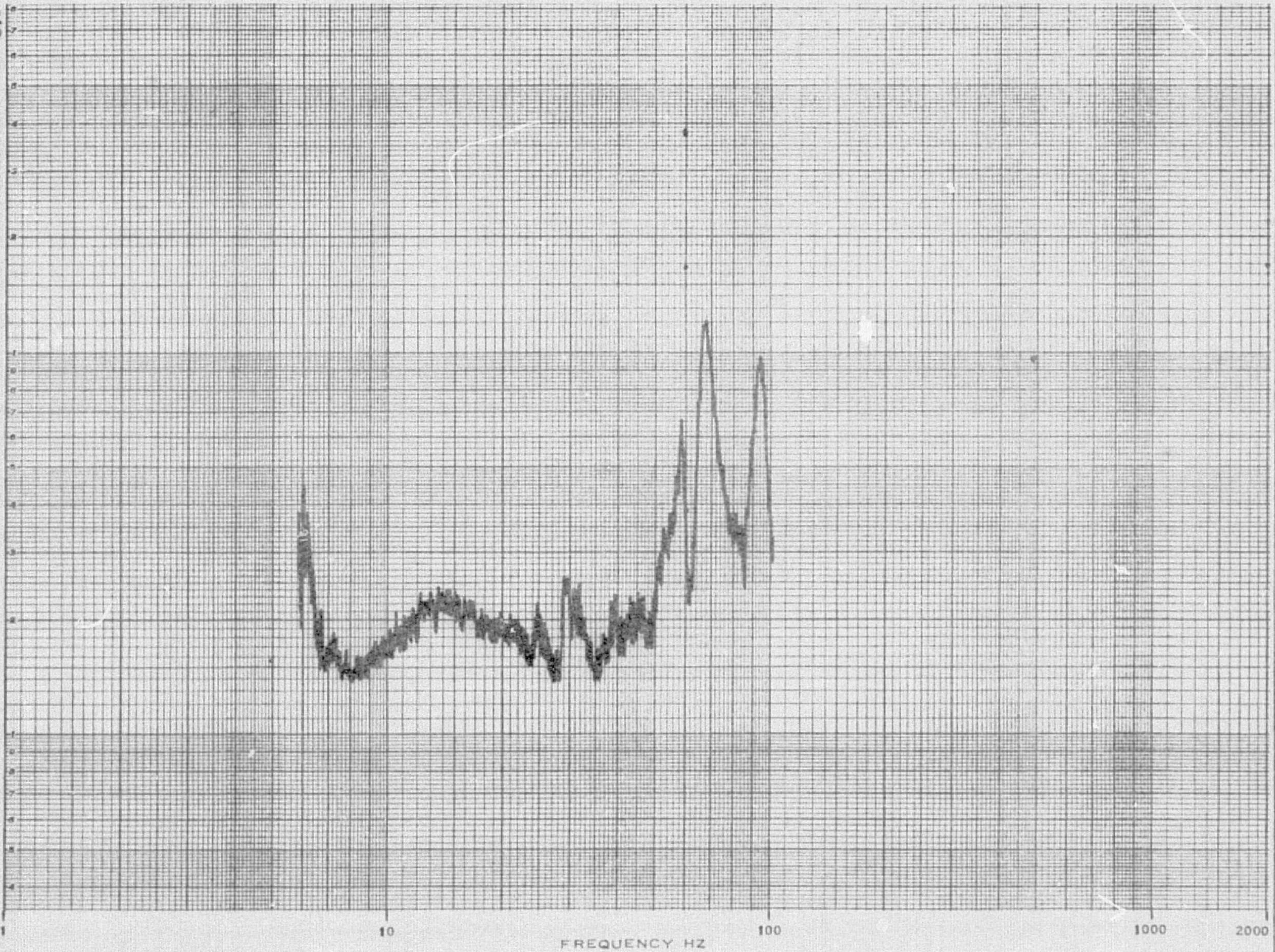
HSF 1633 A 2/69

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION

SINE VIBRATION TEST

RIG	OPERATOR	PLOTTED BY	TRACE NO.	TEST NO.
26	P.J.	P.J.		4

TEST ENGINEER	CHECKED BY	PROJECT	DATE	TIME
T.G.	T.G.	CO_2 DESICCANT	11-23-71	1440



INPUT LEVEL ± 2.0 g	EXCIT. AXIS X
ACCEL S/N NB 90	SENSING AXIS α
ACCEL SENSITIVITY — MV RMS / GP; 2.637 COL / GP	
FILTER 10 HZ B.W.	
FILTER CROSSOVER @ — HZ	
TAPE REEL NO. 012255	SWEEP RATE 3.0 OCT/MIN
COMPR. SPEED VAR DB/SEC	
CHG@ — HZ TO — DB/SEC	
CHG@ — HZ TO — DB/SEC	
NON-OPERATING TEMP. 74 °F	☐ CONTROL ☑ RESPONSE
LOCATION α (CROSSAXIS) TOP BRACKET	
SPECIAL CONDITIONS	

FREQ. RANGE & DIRECTION	ITEM	CODE	SERIAL NO.	TYPE OF TEST
5-100-5 HZ	HS-C DESIC.	—	—	DVT

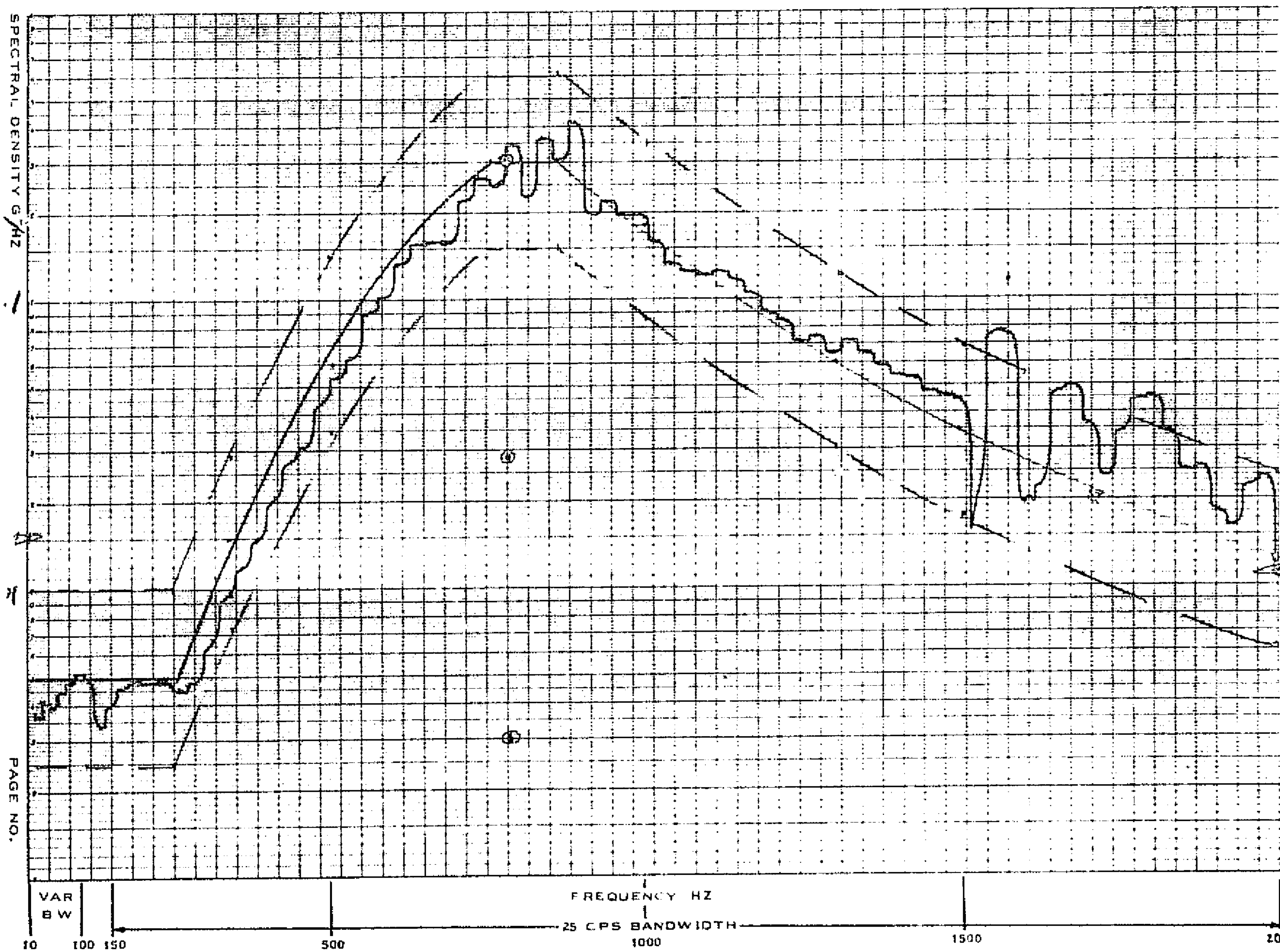
SPECIFICATION	PARA.	AMEND.	PHASE	NAME OF TEST
TEST PLAN	—	—	—	—

REPORT NO. CR-115568 SVHSER-6040

Hamilton Standard

RANDOM VIBRATION TEST ANALYSIS METHOD A

PLOTTED BY: Mickey	CHECKED BY: T.G.	TEST ENGINEER: T Geib	RIG NO.: 26	WITNESS: —	WITNESS: —
PROJECT: CO_2 DESICCANT	ITEM: HS c Co_2 Absorbing assembly	CODE: —	SERIAL NO.: —	TYPE OF TEST: DVT	
SPEC.: TEST PLAN	PARA.: — / PHASE: —	ATA NO.	—	DATE: 11/23/71	TEST NO.: 5



EXCITATION ALONG	X AXIS
GRMS INPUT	12.4
NON-OPERATING	
TEMP.	74 °F
PERIOD OF TEST	[x] START [ ] END
DURATION OF TEST	10 MIN.
ACCEL. SERIAL NO.	PB 34
ACCEL. SENSITIVITY	1 MV RMS/GP; 2333 COL/GP
ACCEL. SENSING	X AXIS
ACCEL. LOCATION	A
TAPE REEL NO.	012255
SPECIAL CONDITIONS	

REPORT NO.
CR-115568
SVHSER-6040

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION

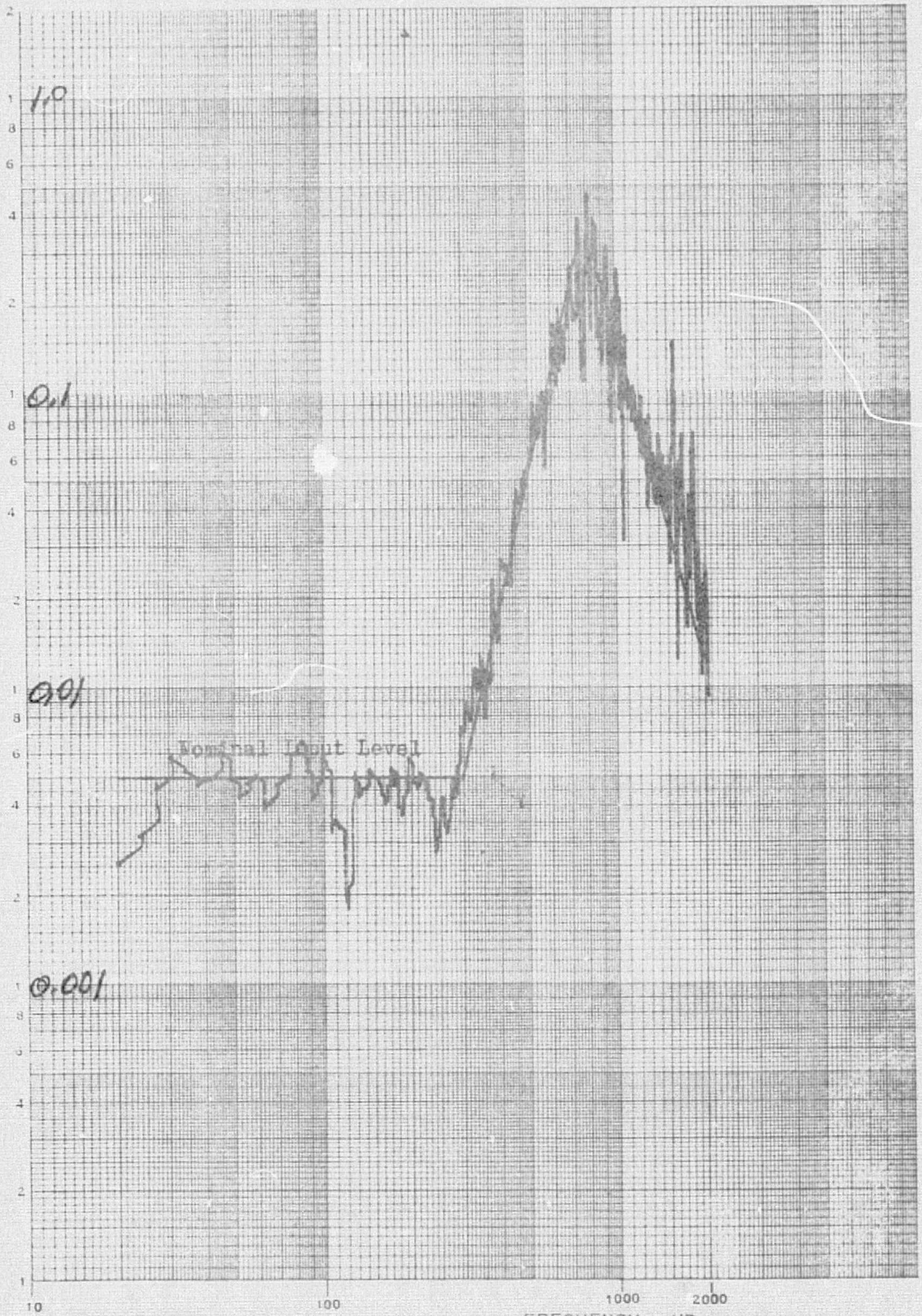
RANDOM VIBRATION TEST ANALYSIS METHOD B

HSF-1635 B

CR-115568
SVHSER-6040

RIG	OPERATOR	PLOTTED BY	TRACE NO.	TEST NO.
26	R. M.	T. G.	1	5

TEST ENGINEER	CHECKED BY	DATE	TIME
T. G.	T. G.	11/23/71	1520



INPUT LEVEL: 12.4 GRMS
EXCITATION AXIS: X
ACCEL SERIAL NUMBER: PB 34
ACCEL SENSING AXIS: X
ACCEL SENSITIVITY: — MV RMS / GP
2.333 COL / GP
ANAL FILTER - HZ B.W.: 6
SWEEP SPEED OCT/MIN
TIME CONSTANT - SEC
ANNAL. CALIBRATION: 16.3 g^2/HZ F.S.
PERIOD OF TEST: ☑ START ☐ END
DURATION: 1.0 MIN
NON OPERATING
TEMP. 74 °F
TAPE REEL NO. 012255
☑ CONTROL ☐ RESPONSE
PICKUP LOCATION: A TOP BRACKET
SPECIAL CONDITIONS

PROJECT	ITEM	CODE	SERIAL NUMBER	TYPE OF TEST
CO_2 DESICCANT	HS-C DESICCANT	—	—	DVT

SPEC.	PARA.	AMEND.	PHASE	RANDOM	PAGE NO.
TEST PLAN	—	—	—	—	A-19

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION

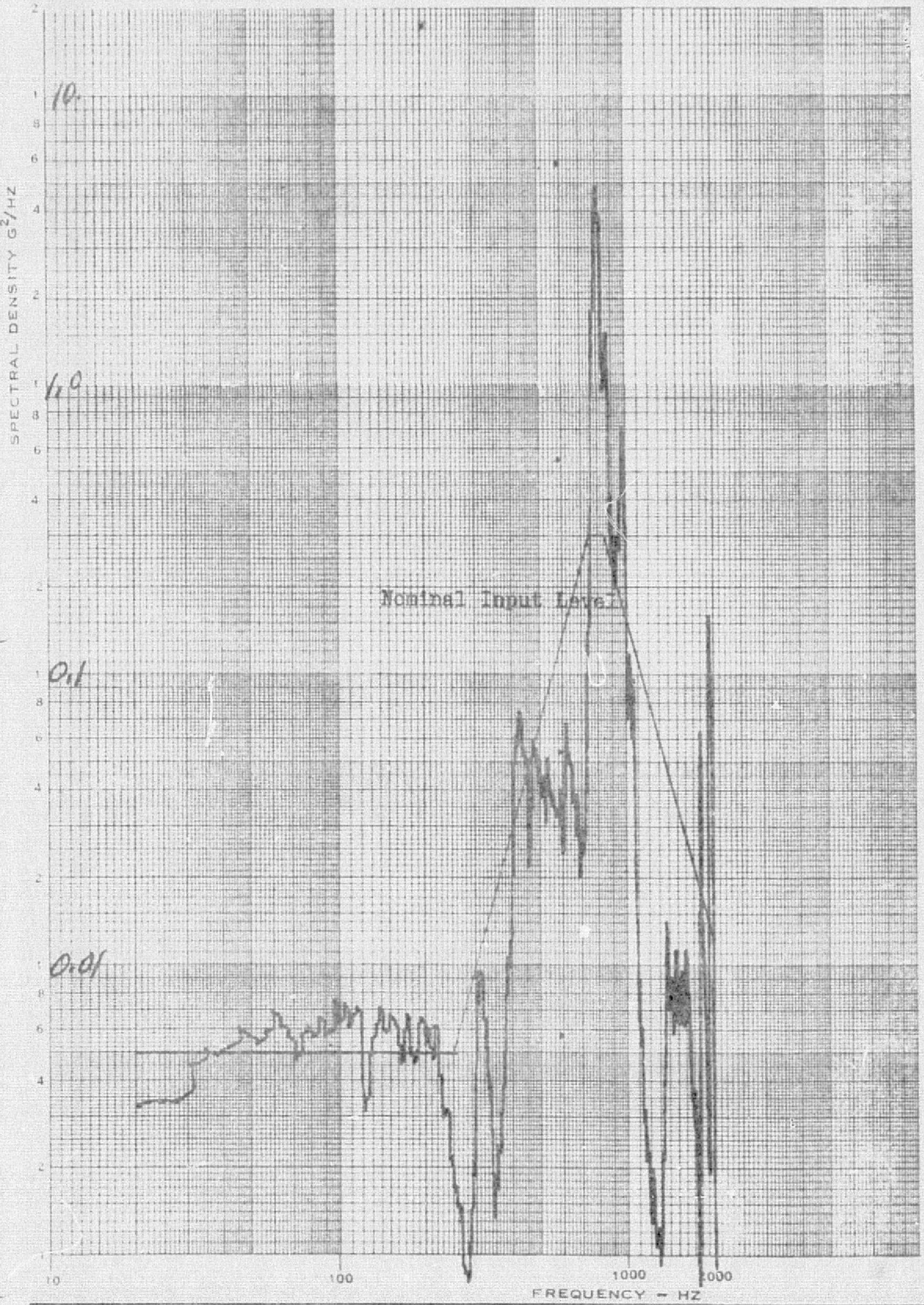
RANDOM VIBRATION TEST ANALYSIS METHOD B

HSF-1635 B

CR-115568
SVHSER-6040

RIG	OPERATOR	PLOTTED BY	TRACE NO.	TEST NO.
26	R. M.	T. G.	2	5

TEST ENGINEER	CHECKED BY	DATE	TIME
T. G.	T. G.	11/23/71	1520



INPUT LEVEL	12.4 GRMS
EXCITATION AXIS	X
ACCEL SERIAL NUMBER	PB 36
ACCEL SENSING AXIS	X
ACCEL SENSITIVITY	— MV RMS / GP; 2.489 COL / GP
ANAL FILTER HZ B.W.	6
SWEEP SPEED OCT/MIN	
TIME CONSTANT - SEC	
ANNAL. CALIBRATION	172. g^2/HZ F.S.
PERIOD OF TEST	[x] START [ ] END
DURATION	1.0 MIN
NON OPERATING	TEMP. 74 °F
TAPE REEL NO.	0/2255
[ ] CONTROL [x] RESPONSE	
PICKUP LOCATION	"B" BOTTOM BRACKET
SPECIAL CONDITIONS	

PROJECT	ITEM	CODE	SERIAL NUMBER	TYPE OF TEST
CO_2 DESICANT	H/S-C DESIC.	—	—	DVT

SPEC.	PARA.	AMEND.	PHASE	RANDOM	PAGE NO.
TEST PLAN	—	—	—	—	

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION

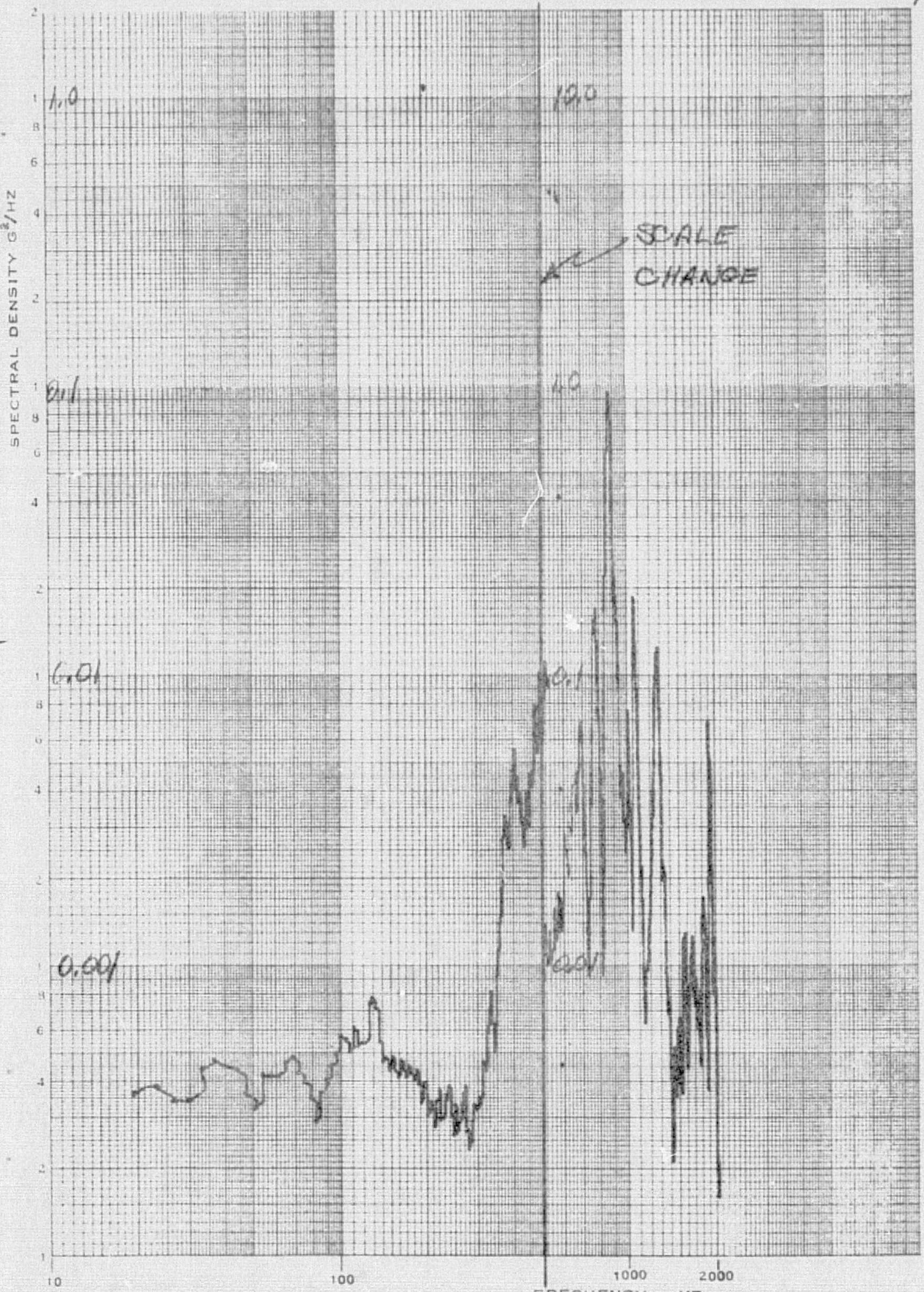
RANDOM VIBRATION TEST ANALYSIS METHOD B

HSF-1635 B

CR-115568
SVHSER-6040

RIG	OPERATOR	PLOTTED BY	TRACE NO.	TEST NO.
26	R.M	T.G.		5

TEST ENGINEER	CHECKED BY	DATE	TIME
T.G	T.G.	11/23/71	1520



INPUT LEVEL: 12.4 GRMS

EXCITATION AXIS: X

ACCEL SERIAL NUMBER: NB82

ACCEL SENSING AXIS: β

ACCEL SENSITIVITY: — MV RMS / GP; 2.848 COL / GP

ANAL FILTER - HZ B.W.: 6 [redacted] | [redacted] | [redacted]

SWEEP SPEED OCT/MIN: [redacted] | [redacted] | [redacted]

TIME CONSTANT - SEC: [redacted] | [redacted] | [redacted]

ANAL. CALIBRATION: 10.9 g^2/HZ F.S.

PERIOD OF TEST: ☑ START ☐ END

DURATION: 1.0 MIN

NON OPERATING — TEMP. 74 °F

TAPE REEL NO. 012255

☐ CONTROL ☑ RESPONSE

PICKUP LOCATION: B (CROSS AXIS) TOP BRACKET

SPECIAL CONDITIONS

PROJECT	ITEM	CODE	SERIAL NUMBER	TYPE OF TEST
CO_2 DESICCANT	HS-C DESIC.	—	—	DVT

SPEC.	PARA.	AMEND.	PHASE	RANDOM	PAGE NO.
TEST PLAN	—	—	—	—	A-21

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

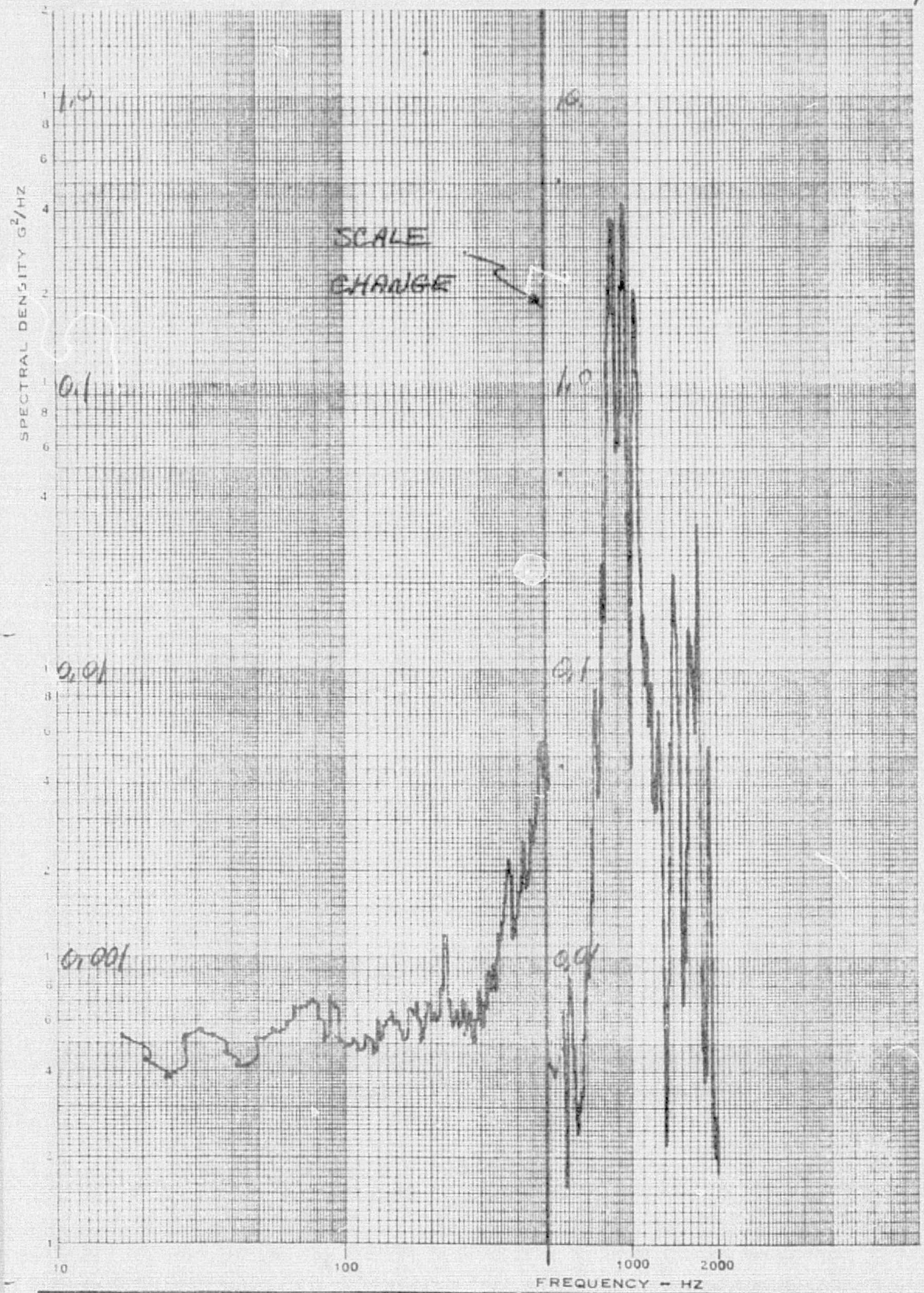
RANDOM VIBRATION TEST ANALYSIS METHOD B

HSF-1635 B

CR-115568
SVHSER-6040

RIG	OPERATOR	PLOTTED BY	TRACE NO.	TEST NO.
26	R.M.	T.G.	4	5

TEST ENGINEER	CHECKED BY	DATE	TIME
T.G.	T.G.	11/23/71	1520



INPUT LEVEL: 12.4 GRMS

EXCITATION AXIS: X

ACCEL SERIAL NUMBER: NB90

ACCEL SENSING AXIS: α

ACCEL SENSITIVITY: — MV RMS / GP

2.637 COL / GP

ANAL FILTER HZ B.W.: 6 [redacted] | [redacted] | [redacted]

SWEEP SPEED OCT/MIN: [redacted] | [redacted] | [redacted]

TIME CONSTANT - SEC: [redacted] | [redacted] | [redacted]

ANNAL. CALIBRATION: 141.5 g^2/HZ F.S.

PERIOD OF TEST: ☑ START ☐ END

DURATION: 1.0 MIN

NON OPERATING | TEMP. 74 °F

TAPE REEL NO.: 012255

☐ CONTROL ☑ RESPONSE

PICKUP LOCATION: α CROSSAXIS TOP BRACKET

SPECIAL CONDITIONS

PROJECT	ITEM	CODE	SERIAL NUMBER	TYPE OF TEST
CO_2 DESICCANT	HS-C DESIC.	—	—	DVT

SPEC.	PARA.	AMEND.	PHASE	RANDOM	PAGE NO.
TEST PLAN	—	—	—	—	

HSF-175.1A 1/66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: DVT Y ... Test
TEST ENGINEER: T. Geib.
NAME OF RIG: # 26
PROJECT & ENG. ORDER NO.: B77-400-100A

SHEET 1 OF
DATE 11-23-71
TEST PLAN NO. Per Plan of ... st
MODEL NO. Virgin HS-C CO2 ad-
PART NO. Sorbing desiccant
SERIAL NO.
OPERATORS P. Judoin, R. Micket

Run #	Time Start		Axis	mode		G's Peak	Scan Rate oct/min		G's Rms	Time in min's
2	1355		x	Sine		1.0	3.0		-	-
4	1440		x	Sine		2.0	3.0		-	-
5	1520		x	Rand		-	-		12.4	1.0

REMARKS:

CR-115568
SVHSER-6040

1290

PROJECT ITEM HS-C CO2 S/N

Absorbing desiccant

VIBRATION TEST LOG

CODE DATE 11/28/71

CR-115568
SVHSER-6040

MASTER PAGE NO 173

LOG PAGE NO. 196?

TEST TITLE DVT ENGINEER T Geib

OPERATOR R. Micket / P Jobosn

NO	RUN NO	TIME	TEST CODE	PREAMPLIFIER SETTINGS 1	2	3	4	5	6	7	8	9	10	11	12	VIB AXIS	INPUT LEVEL	SCAN RATE	COMP SPEED	CONTROL FILTER	TAPE SPEED	TAPE TIME	VISICORDER SPEED	RIG	REMARKS
0	1		CaL	1000	1000									A		-	-	-	-		15			#96	1 VolT PK. aT 200 HZ.
1 2	2	1355	Run	10	10	-	-	-	-	-	-	-	-	C	-	X	1.0	3.0	VARi	10/100	i ps	3.0	-		5/2k iTEM/FIXTURE SCAN CONTROL @ "A"
2	3	1430	CaL	1000	1000		1000	1000						C							I				1 VolT PK. aT 200 HZ.
5 5	4	1440	Run	10	10	-	10	10	-	-	-	-	-	o l	-	X	2.0	3.0	VARi	10/100	n t	2.5	-		5/100HZ/5 SiNE CONTROL @ "A"
	5	1520	Run	30	100		30	100						d		x	GRms 12.4	-	-	-	er m	1.0			1 min. Random Run
																					ed i				
																					a Te				
																					Ba				
																					nd				

HSF 1758

A-24

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

CR-115568
SVHSER-6040

SINUSOIDAL DATA REDUCTION LOG

MASTER PAGE NO. 1733 PROJECT -- TEST DATE 11-23-71 D.R. DATE

TAPE REEL NO. 012255 ITEM HS-C CO_2 absorbing desiccants SERIAL NO. — W.P.I. B77-400-100A

CAL VOLTAGE [redacted] OR 1000 MVpk (AT 200 Hz)

CALCULATION

$$CAL_{pt} = \frac{RUN}{CAL} \times \frac{CAL\ VOLTAGE}{ACCEL\ SENS} \quad \frac{MV_{rms}}{MV_{rms}/G_{pk}} \quad OR \quad \frac{MV_{pk}}{Coul/G_{pk}}$$

CAL on RUN #3

TRACE	RUN	CHAN	S/N ACCEL	SENS ACCEL	RUN/CAL ATT	(RUN/CAL) (ACCEL SENS)	CAL/RUN LOG ATT	CAL/RUN RANGE ATT	CAL PT	F.S.
1	4	1	PB34	2.333	10 / 1000	$\frac{1\times10^{-2}}{2.333} = .429\times10^{-2}$	1 / 1	20 / 20	4.29	1.0
2		2	PB36	2.489	10 / 1000	$\frac{1\times10^{-2}}{2.489} = .402\times10^{-2}$	1 / 1	20 / 20	4.02	1.0
3		4	NB82	2.848	10 / 1000	$\frac{1\times10^{-2}}{2.848} = .351\times10^{-2}$	1 / 1	20 / 0	3.51	.1
4		5	NB90	2.637	10 / 1000	$\frac{1\times10^{-2}}{2.637} = .38\times10^{-2}$	1 / 1	20 / 0	3.80	.1

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION

CR-115568
SVHSER-6040

RANDOM DATA REDUCTION LOG

MASTER PAGE NO. 1733 PROJECT — TEST DATE 11-23-71 D.R. DATE 11-29-71

TAPE REEL NO. 012255 ITEM HS-C CO_2 absorbing desiccant SERIAL NO. -- W.P.I. B77-400-100A

CAL VOLTAGE [redacted] OR 1000MVpk (AT 200Hz) DEG. OF FREE. 128

CALCULATION CONST. [redacted] $\frac{MV^2 rms(Grms)^2}{HZ(Gpk)^2}$ OR $9.82(10)^4$ $\frac{MV^2 pk\ (Grms)^2}{HZ\ (Gpk)^2}$ Based on E.BW=6.4

CALCULATION CONST. [redacted] OR [redacted] Based on E.BW[redacted]

CAL on RUN #3

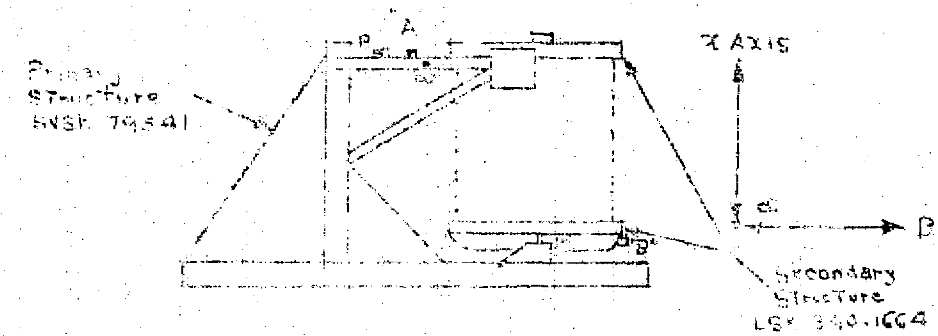
TRACE	RUN	CHAN	S/N ACCEL	SENS. ACCEL	RUN/CAL ATT.	$\frac{(RUN/CAL)^2}{(ACCEL\ SENS)^2}$	CAL/RUN INPUT ATT.	CAL/RUN OUTPUT ATT.	CAL PT	F.S.
1	5	1	PB34	2,333	30 / 1000	$\left(\frac{3\times10^{-2}}{2,333}\right)^2 = 1.66\times10^{-4}$	(3) 10 / (4) 20	0 / 20	16.3	1.00
2		2	PB36	2,489	100 / 1000	$\left(\frac{1\times10^{-1}}{2,489}\right)^2 = 17.5\times10^{-4}$	(4) 10 / (4) 10	0 / 10	172.	10.
3		4	NB82	2,848	30 / 1000	$\left(\frac{3\times10^{-2}}{2,848}\right)^2 = 1.11\times10^{-4}$	(3) 10 / (3) 10/20	0 / 10	10.9	1.0/10
4		5	NB90	2,637	100 / 1000	$\left(\frac{1\times10^{-1}}{2,637}\right)^2 = 14.4\times10^{-4}$	(3) 10 / (3) 10/10	0 / 20/10	141.5	1.0/10

DATE 11/18/71 | MASTER VIBRATION LOG | MASTER PAGE NO. 233

PROJECT 23 | ITEM Absorber | S/N | CODE | WPI | RIG 26 | LOG PAGE NO. 73

TEST TITLE | ENGINEER T. Geri | OPERATOR R. Micket

No.	MEASUREMENT			TRANSDUCER														REMARKS
	VARIABLE		LOC	TYPE	S/N	ELECT VOLTS	SENS											
1	Accel	Ca 1	"A"	2226	PB34		2.323											
2	Accel	Ca 2	"B"	2226	PB36		2.429											
3																		
4	Accel	Ca 3	B	2226	N032		2.848											
5	Accel	Ca 4	α	2226	N036		2.637											
6																		
7																		
8																		
9																		
10																		
11																		
12																		



Hamilton Standard

CR-115563
SVHSER-6040

A-27

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APPENDIX B

REPRODUCIBILITY

REPRODUCIBILITY

For preparation of HS-C for Test Series III, five batches were made. Capacity tests at standard conditons (p 53) showed excellent reproducibility (±2.5%), as shown in Table B-I.

SERIES III LARGE SCALE PREPARATION SUMMARY

Preparation Number*	CO_2 Capacity % by Wt.	H_2O Capacity % by Wt.	Density g/ml	Date Prepared	Weight Prepared
P-9130-II-A	1.96	4.60	.372	2/2/72	1.25 lb
P-9130-II-B	1.90	-	.374		
P-9130-III-A	1.88	-	.376	2/3/72	1.25 lb
P-9130-III-B	-	-	-		
P-9130-IV-A	1.87	-	.378	2/3/72	1.25 lb
P-9130-IV-B	-	-	-		
P-9130-V-A	1.88	-	.388	2/4/72	1.25 lb
P-9130-V-B	-	-	-		
P-9130-VI-A	1.89	-	.378	2/7/72	1.25 lb
P-9130-VI-B	1.86	-	.378		

*NOTE: This Series was prepared in 1.25 pound batches which were given the designation, i.e., P-9130-II. Each batch was stored and subsequently tested in 0.50 liter containers labeled, i.e., P-9130-II-A or P-9130-II-B.

TABLE B-I

APPENDIX C

AMMONIA TESTING PER D-NA-002

TOXICANT TESTING

HS F-927 6/66 Hamilton Standard A®

CR-115568 REV I
SVHSER-6040 10-11-71

TEST NO. 2

HAMILTON STANDARD

PLAN OF TEST

JOB: Desiccant Humidity Control

PLAN PREPARED BY: R. J. Lunde

PROJECT & ORDER: 877-400-100A

APPROVED BY:

INSTRUCTION: Toxicant testing

TEST ENGINEER: C. DeSimone

TIME PERIOD: 9-27-71 TO 10-31-71

1. WHAT IS ITEM BEING TESTED?
2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?
3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.
4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.
5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.
6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1. HS-C Preparation 1102

2. Purpose

It is conceivable that the HS-C bed may be heated as much as 100°F above normal operating temperature during undefined failure mode operation. The work statement requires that HS-C not cause cabin contamination in such a failure mode and sets maximum for several toxicant levels 60 minutes and 168 hours after such a failure.

3. Test setup

The latest shuttle figures are

cabin volume 1800 ft^3

CO_2 removal rate 0.53 lbs/hr.

Therefore,

$$\text{HS-C bed} = \frac{0.53\ \text{lb } CO_2}{\text{hr}} \times \frac{\text{hr}}{2\ \text{beds}} \times \frac{\text{lb HS-C}}{0.017\ \text{lbs } CO_2} \times \frac{454\ \text{gm}}{\text{lb}} = 7070\ \text{gm}$$

(Presuming an HS-C capacity of 1.7% CO_2 by wt).

Test bed weight is about 2 gm. Therefore

$$\begin{array}{l}\text{Equivalent} \\ \text{cabin volume}\end{array} = 2\ \text{gm HSC} \times \frac{1800\ ft^3\ \text{cabin}}{7070\ \text{gm HSC}} = 0.51\ ft^3$$

ORIGINAL PAGE IS OF POOR QUALITY

AMMONIA TESTING

Test Procedure

1. HS-C was tested for ammonia as follows. A 5.0 gram sample of resin was placed in a 1000cc stainless steel cylinder and evacuated to 38 mm pressure, back filled to 14.7 psia with bone dry air and stored at 155°F for 72 hours. The pressure was vented to 14.7 psia after an initial heating period of 2 hours. Following the heat soak, the container was removed from the oven and stored at room temperature for 24 hours. A sample of the gas over the resin was then transferred to a 10 cm. IR cell (10 psia pressure).

2. A NASA standard gas was used to calibrate HSD IR equipment at 500 ppm NH_3 in a 10 cm cell.

3. A newly purchased HSD gas was used to calibrate HSD IR equipment at 94 ppm. Agreement with NASA's 500 ppm sample was $<\pm 10\%$ cm cell.

Test Results

1. "Wet HS-C"*, when tested to D-NA-002 gave 2120 ppm NH_3 above HSD sample containers.

2. "Dry HC-C"**, when tested to D-NA-002 gave 1200 ppm test.

3. "Wet HS-C", after test, was evacuated for 30 minutes and let up to room air for 30 minutes equilibration. This gas then measured $\leq$ 10-20 ppm NH_3 when a 5x expansion was used with the 10 cm IR cell.

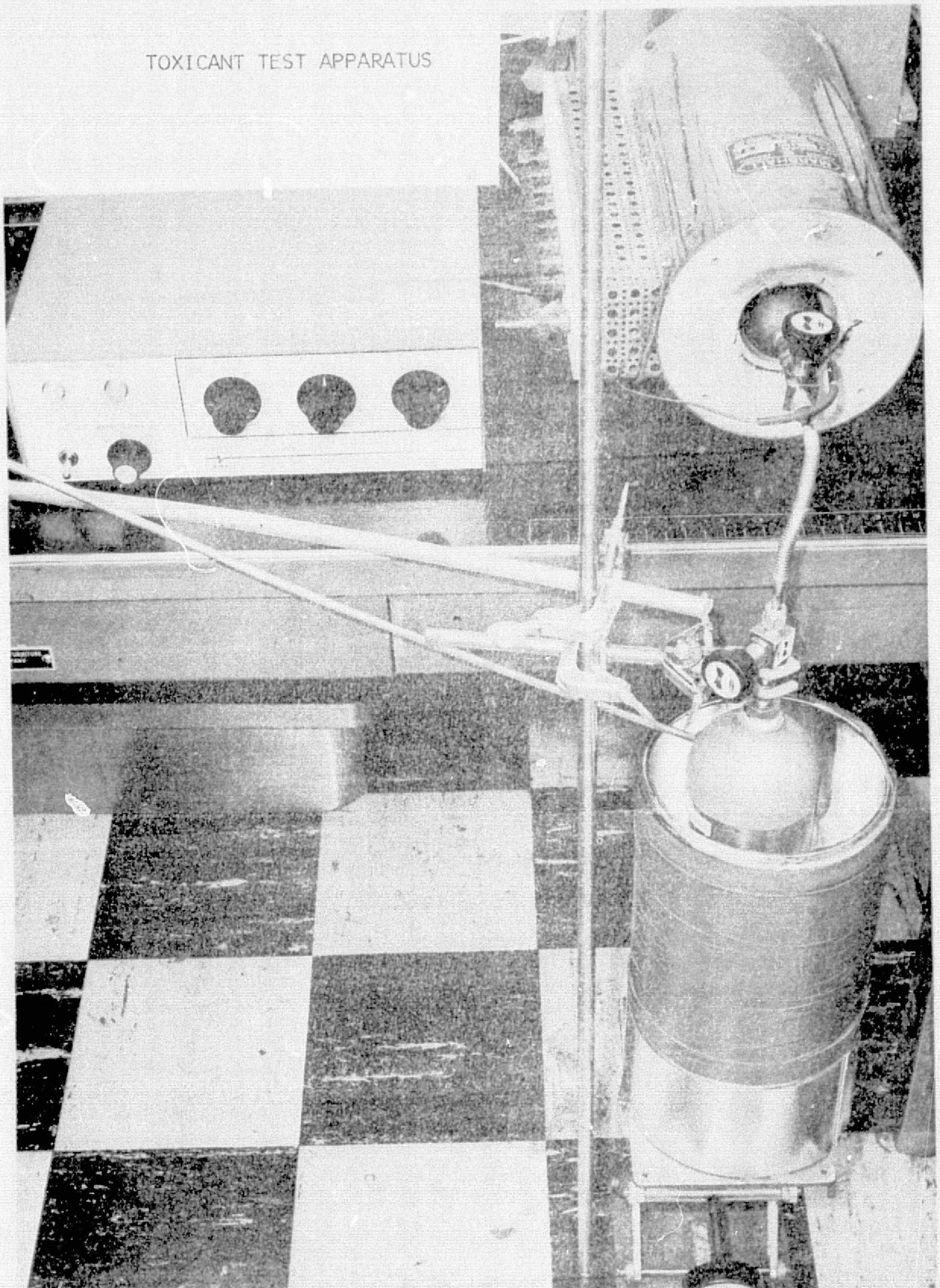
4. "Wet HS-C" gives $\frac{267 \text{ microgram } NH_3}{\text{gm sample}}$

   "Dry HS-C" gives $\frac{152 \text{ microgram } NH_3}{\text{gm sample}}$ when data from 4. and 5. above are reduced.

*Equilibrated 24 hr. in N_2 with 50°F dewpoint H_2O

**Evacuated 24 hr. at room temp.

TOXICANT TEST APPARATUS



CR-115568
SVHSER-6040

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

INTERNAL CORRESPONDENCE

Please address answer to
Mail Stop No. 1a-2-5

December 30, 1971
SVME 623

Memorandum to: Dr. P. J. Lunde

cc: Messrs. W. A. Blecher
R. L. Fischer
F. Kester
P. Perkins

Subject: Toxicant Testing on HSC and Rig 88

Four gas samples, one from rig 88 and three from an outgassing study on HSC Sample Prep 7489-92 (tested in rig 88) were sent to Analytical Research Laboratories, Inc., 160 Taylor Street, Monrovia, California for toxicant analysis. The results of the gas analysis are given in the attached report. The results of a blank analysis on the empty sample cylinders prior to the actual test are also included. The conditions under which the rig 88 sample was taken are available from Advanced Engineering; the procedure by which the HSC samples were obtained is as follows: three separate samples of 0.20 g of HSC were heated for periods of 1, 7 and 24 hours in a test rig of total volume of 0.05 cu. ft. at 180°F in air at 760 mm. The test rig consisted of a 400 cc stainless steel cylinder containing the sample and which was placed in an oven. This was connected to a 1000 cc stainless steel cylinder by a short length (8 in) of SS, 1/4" tubing which was outside of the oven.

In the case of the sample heated for 1 hr., a portion of the larger cylinder was immersed in liquid nitrogen for the duration of the test. The same procedure was followed during the last 2 hrs. of the 7 hr. test and the last 4 hrs. of the 24 hour test. This procedure was used to provide a driving force for the transfer of the offgassed products from the small cylinder through the tubing connecting it to the larger cylinder.

The presence of the brominated compounds in the HSC sample is explained on the basis that this sample had been tested in rig 88 where it adsorbed and held these contaminants. If the brominated compounds are neglected, the HSC samples still fail the test on the basis of the ammonia content, aromatics and total hydrocarbons.

Prepared by: A. Ruby
A. Ruby

Approved by: P. Perkins
P. Perkins

AR:han

TABLE No. 1

Maximum allowable toxicant levels, HSC

Material	mg/M^3
Carbon Monoxide	3.2
Total Hydrocarbons	14.7
Ethylene Glycol	2.5
Halocarbons	0.536
Inorganic Acids	0.0082
Aromatic Hydrocarbons	0.319
Ketones	5.88
Ammonia	1.73
Aldehydes	0.0123
Oxides of Nitrogen	0.094
Hydrazine	0.0655
Alcohols	1.31
2-butanone	29.4
Carbonyl Fluoride	6.75
2-methyl butanone	35.2
1,1,2-trichloroethane	153.
1,2,2-trifluoroethane	153.

Hamilton Standard

CR-115568
SVHSER-6040

ANALYTICAL RESEARCH LABORATORIES, INC.

160 TAYLOR STREET, P.O. BOX 369, MONROVIA, CALIFORNIA 91016 • 213 357-3247

Lab/Shipper Log Number
101022

Material/Sample Identity			Date Received
Hamilton Standard/4 gas cylinders			10/21/71
P.O. or R.P. Number: SS008576NL	Requested By: Armand Ruby		
Work Order: 5098-01	Sample Disposition: ☐ Retain ☐ Return ☐ Destroy	Nature of Hazard	Due Date

Ship To:

Hamilton Standard, P.O. Box 343
Windsor Locks, Connecticut 06096

Mark For:

Nature of Work and Information Desired

Background Sampling of Gas Sample Cylinders

SUMMARY OF LABORATORY REPORT

The four sample cylinders received from you were evacuated to approximately 10^{-5} torr, flushed twice with helium, filled to 15 psig with helium, and transferred to an oven maintained at 35°C for 12 hours. Following this exposure, the bottles were placed on a gas chromatograph gas sample system and their contents cryogenically trapped for analysis. These analyses are shown on the attached tables. The values reported are the total micrograms of each component found in the one liter of gas transferred through the cryogenic trap.

This document and the attached data represents a certification of the trace analysis and cleanliness on the examined gas cylinders.

These sample cylinders were returned for sampling the outgassing of your sorbent bed. We are looking forward to an early receipt of the collected samples.

Analyst	Date	Approved By	Invoice #
C. L. Deuel	11/18/71	[signature]	

CR-115568
SVHSER-6040

COMPOUND	MW	UG
FREON 113	187.39	.00007
CHLOROFORM	119.39	.00028
TRICHLOROETHYLENE	131.40	.00011
DICHLOROBENZENE	147.01	TRACE
BUTANE	58.12	.0014
ISOPRENE	68.11	.0095
METHYLCYCLOPENTANE	84.11	.0043
METHYLCYCLOHEXANE	98.18	.0017
BENZENE	78.11	.021
TOLUENE	92.13	.025
CUMENE	120.20	.019
ETHYL ALCOHOL	46.07	.017
ISOPROPYL ALCOHOL	60.09	.010
ACETONE	58.08	.015
	TOTAL	.12527

MILTON SQUARE, SAMPLE BOTTLE NO. 2

PAGE

CR-115568
SVHSER-6040

COMPOUND	MW	UG
FREON 113	187.39	.17
CHLOROFORM	119.39	.0029
TRICHLOROETHYLENE	131.40	.00006
BUTANE	58.12	.0084
TOLUENE	92.13	.0084
	TOTAL	.19480

CR-115568
SVHSER-6040

COMPOUND	M.W	UG
FREON 113	167.39	.091
CHLOROFORM	119.39	.00014
TRICHLOROETHYLENE	131.40	.00011
TOLUENE	92.13	.0017
	TOTAL	.09293

...ILTON S...DARD, SAMPLE BOTTLE NO. 4

COMPOUND	MW	UG
FREON 113	187.39	.00007
CHLOROFORM	119.39	.00014
TRICHLOROETHYLENE	131.40	.00011
TETRACHLOROETHYLENE	165.85	.00003
TOLUENE	92.13	.00032
	TOTAL	.00067

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION UA

CR-115568
SVHSER-6040

ANALYTICAL RESEARCH LABORATORIES, INC.
160 Taylor Street, P.O. Box 369
Monrovia, Calif. 91016

Laboratory/Shipper Log Number
101022A

Material/Sample Identity Hamilton Standard/4 gas samples	Date Received 12-3-71
P.O. or R.P. Number SS008576NL	Requested By Ron Corriveau/cc: Armand Ruby

Work Order	Sample Disposition	Nature of Hazard	Due Date
5098-01	☐Retain ☐Return ☐Destroy		

Ship To: Hamilton Standard, P.O. Box 343,
Windsor Locks, Connecticut 06096

Mark For:

Nature of Work and Information Desired

Trace Gas Analysis of Supplied Samples

Summary of Laboratory Report

The four gas samples were divided on a vacuum rack to provide aliquots for at least two gas chromatographic examinations one for wet chemical and one for mass spectrometric analyses. The results of these studies are found in Tables 1-3.

The brominated compounds listed in Table 1 were identified by mass spectrometry. The dibromoethylene compounds were unequivocably identified, but the assignment of the proper isomers could not be made by mass spectrometry. The cis and trans isomers of 1,2 dibromoethylene were assigned primarily because the resolution of these two peaks by gas chromatography indicated a probable spread in boiling points. The 1,1 isomer's boiling point is quite close to that of the 1,2 isomer, while the cis-trans isomers offer a larger spread. It could, however, be considered equally significant that in samples 2,3 and 4 only one isomer was present. Since the cis-trans forms are generally mingled, a choice of the 1,1 and 1,2 isomers might be indicated.

The unknown listed in samples 1 and 2 is the same compound. It was not resolved by gas chromatograph from the tribromoethylene peak, and was not identified by mass spectrometry. There was some indication that it is probably a brominated acetylene type compound.

Analyst	Date	Approved By	Invoice No.
C. L. Deuel	12-22-71	[signature]	

C-12

GC - MS TRACE ANALYSIS OF HAMILTON STANDARD
SAMPLES, mg/m^3

SAMPLE NUMBER

Compound	1. R1G88 11-17	2. HSC 7 hrs. @ 180°	3. HSC 24 hrs. @ 180°	4. HSC 1 hr. @ 180°
Methylene Chloride	-	3.8	0.039	-
Methyl Chloroform	0.0067	0.0015	0.026	0.0080
Tetrachloroethylene	0.00027	-	0.097	0.37
1,1 Dichloroethane	0.00057	-	0.0009	-
Trans dibromoethylene	770.	-	-	-
Cis dibromoethylene	820.	2.2	0.2	0.0022
Tribromoethylene	1350.	62.	100.	39.
Toluene	0.30	0.82	1.1	1.5
Methyl alcohol	0.026	-	0.51	0.73
Isopropyl alcohol	0.48	0.50	0.076	0.089
Acetone	0.67	0.92	0.65	0.80
Unknown	6.5	.13	-	-
Carbon Monoxide*	N.D.	N.D.	N.D.	N.D.

*N.D. = None Detected, or less than 5 ppm with the analytical system used.

TABLE 1

Hamilton Standard

CR-115568
SVHSER-6040

MASS SPECTROMETRIC ANALYSIS OF HAMILTON STANDARD SAMPLES, Vol %

SAMPLE NUMBER

Compound	1. R1G88 11-17	2. HSC 7 hrs. @ 180°F	3. HSC 24 hrs. @ 180°F	4. HSC 1 hr. @ 180°F
Hydrogen	0.14	N.D.*	N.D.*	N.D.*
Helium	N.D.*	0.05	0.45	0.05
Nitrogen	79.2	78.1	77.8	77.9
Oxygen	20.2	20.8	20.7	21.0
Argon	0.03	0.91	0.90	0.90
Carbon Dioxide	0.38	0.11	0.17	0.15
Water	0.04	0.01	0.04	0.03

*N. D. = None Detected, $<.005\%$

TABLE 2

WET CHEMICAL ANALYSIS OF HAMILTON STANDARD

SAMPLES, ppm

SAMPLE NUMBER

Compound	1. RIG88 11-17	2. HSC 7 hrs. @ 180°F	3. HSC 24 hrs. @ 180°F	4. HSC 1 hr. @180°F
Ammonia	88	28	73	31
Oxides of Nitrogen (as NO_2)	<1	2	<1	3
Aldehydes (as Formaldehyde)	<1	<1	<1	<1

TABLE 3

APPENDIX D

INPUT/OUTPUT PARAMETERS

FLOW CHARTS FOR COMPUTER PROGRAM

INPUT/OUTPUT PARAMETERS

Input Parameters

Program Control Constants.-

Data Loc.	Symbol	Definition	Units
1.	DT	Calculation time interval	min
2.	TMAX	Maximum time duration of transient	min
3.	PRINT	Input 1.0 to print system output variables each DT; input N to print system output variables each N(DT) minutes (N=any positive integer)	
4.	PLOT	Input 0. - No printer plots outputed Input 1. - Printer plots specified in section 1.2 outputed	
5.	FN	Number of nodes	
6.	IND	Input 0. - system initially adsorbs Input 1. - system initially desorbs	
7.	IDES	Input 0. - system vacuum desorbs Input 1. - system gas purge desorbs	
8.	ISOT	Input 0. - system performs isothermally Input 1. system performs nonisothermally	
9.	XJ	Number of passes through PVAC each system pass	
12.	PRILST	Same as print but for last full cycle.	

Initial Conditions. -

Data Loc.	Symbol	Definition	Units
11.	ICXC	Initial loading of CO_2 on X sites	%
12.	ICYH	Initial loading of H_2O on Y sites	%
13.	ICZC	Initial loading of H_2O on Z sites	%

Data Loc.	Symbol	Definition	Units
14.	ICYHC	Initial loading of CO_2 on YH20 sites	%
15.	PIH2O	Inlet Partial pressure of H_2O	mmHg
16.	PICO2	Inlet partial pressure of CO_2	mmHg
	Program Constants.-		
21.	XOL	Ultimate loading capacity of CO_2 on X sites	%
22.	YOL	Ultimate loading capacity of H_2O on Y sites	%
23.	ZOL	Ultimate loading capacity of H_2O on Z sites	%
24.	KX	Forward rate coefficient for CO_2 on X sites	$\frac{1}{mmHg}$
25.	KXR	Reverse rate coefficient for CO_2 on X sites	$\frac{1}{mmHg}$
26.	KY	Forward rate coefficient for H_2O on Y sites	$\frac{1}{mmHg}$
27.	KYR	Reverse rate coefficient for CO_2 on Y sites	$\frac{1}{min}$
28.	KYH	Forward rate coefficient for CO_2 on YH_2O sites	$\frac{1}{min\text{-}mmHg}$
29.	KYHR	Reverse rate coefficient for CO_2 on YH_2O sites	$\frac{1}{min}$
30.	KZ	Forward Rate coefficient for H_2O on Z sites	$\frac{1}{min\text{-}mmHg}$
31.	KZR	Reverse rate coefficient for H_2O on Z sites	$\frac{1}{min}$

Data loc.	Symbol	Definition	Units
32.	MZT	Bed weight	lb
33.	PAIR	Process gas pressure at bed inlet	mmHg
34.	Q	Process gas flow	ft^3/min
35.	TCIN	Coolant inlet temperature	°R
36.	TGI	Process gas inlet temperature	°R
37.	PIN	Bed inlet total pressure during vacuum desorption	mmHg
38.	POUT	Bed outlet total pressure during vacuum desorption	mmHg
39.	ADSORB	Adsorption cycle time	min
40.	DESORB	Desorption cycle time	min
41.	VB	Bed void volume	ft^3
42.	XMU	Viscosity	$lb\text{-}sec/in^2$
43.	DIA	Bead diameter	inches
44.	LB	Bed length	ft
45.	WeTOT	Coolant flow rate	lb/min
46.	CPC	Specific heat of coolant flow	BTU/lb-°F
47.	LB	Bed length	ft
48.	ABHXT	Heat transfer area between bed and heat exchanger	ft^2
49.	AAMBT	Heat transfer area between heat exchanger and ambient	ft^2
50.	WHX	Heat exchanger core weight	lb
51.	WBED	Bed weight	lb
52.	CPHX	Heat exchanger specific heat	BTU/lb-°F
53.	CPBED	Bed specific heat	BTU/lb-°F

Data Loc.	Symbol	Definition	Units
54.	AB	Bed cross sectional area	ft^2
55.	AHX	Heat exchanger cross section area	ft^2
56.	KB	Bed axial conductance	BTU/min-ft-°F
57.	KHX	Heat exchanger metal thermal conductivity	BTU/min-ft-°F
58.	TAMB	Ambient temperature	°R
59.	HAMB	Ambient heat transfer coefficient	BTU/min-ft^2 °F
60.	NPT1	No. of points in h_B vs W_T curve	
61.	NPT2	No. of points in h_{HX} vs W_c curve	
62.	PRLAST	Durling last cycle print every PRLAST (DT)	N.D.
63.	A	Cross sectional area of bed	$in.^2$
64.	E	Void fraction	N.D.

Curve Inputs.-

1. Heat transfer coefficient, h_B vs flow rate

Data Location	Input
101 to 120	Values of flow through bed (lb/min)
121 to 140	Values of heat transfer coefficient corresponding to values of flow in data location 101 to 120.

2. Heat transfer coefficient, h_c vs coolant flow rate

Data Location	Input
141 to 160	Values of coolant flow (lb/min)
161 to 180	Values of heat transfer coefficient corresponding to values of flow in data location 141 to 160.

A description of the subroutine LOAD follows along with an example of the inputing of data. The example used is for the test case included in the source listings.

NAME: LOAD
CATEGORY: Input/Output
TITLE: Standard Load Routine
PURPOSE: This routine loads a variable amount of floating point decimal input.
METHOD: To load variables, 2 dimensional or 3 dimensional or arrays programmer must use qEQUIVALENCE statements to assign these parameters storage as part of the one dimensional array used as an argument to LOAD.

Program Information

The two items in this group specify the number (n) of pieces of data to be loaded per card or line, and where in the computer memory, location number, to put this input data. The location number is also used to terminate loading and start computing the results. See HS Form 1199A 9/63.

A) "n" specifies the number of pieces of input data to be loaded on this card or line and is a number from 1 to 5 written without a decimal point. "n" is coded in card column 1.

B) Location number, specified by the particular program, defines where the first piece of input data will be loaded in the computer memory. Successive pieces of input data will be loaded into successive locations in memory. The location number is coded in card colums 3 through 12. Other features and requirements are:

1. The location number must be written with a decimal point.
2. If the location number is omitted, the input data on this card will be loaded consecutively in memory following the previously loaded input data.
3. A minus sign before the location number terminates loading at the end of this card line, and the computer will proceed to calculate the results of the analysis.
4. The input data is coded such that the first piece of data is in card columns 13 through 24, the second in card columns 25 through 36, etc.

USAGE: CALL LOAD (DATA)
DATA - 1 dimensional array - floating point into which data is to be loaded.

Output Parameters

The following system variables are printed out each print interval (set up by PRINT (3)).

SYMBOL	DEFINITION	UNITS
TIME	Transient elapsed time	min
PCTL	Total percent loading on bed	%
EFFH	H_2O removal efficiency	%
EFFC	CO_2 removal efficiency	%
LTH2O	Total loading of H_2O on bed	%
LTCO2	Total loading of CO_2 on bed	%
LTYH2	Total loading of H_2O on Y sites	%
LZH2	Total loading of H_2O on Z sites	%
LXCO2	Total loading of CO_2 on X sites	%
LYHC	Total loading of CO_2 on YH_2O sites	%
TCOUT	Average outlet coolant temperature	°R

The following variables are printed nodally or at nodal interfaces

Weight percent adsorbed by nodes

LTCO2	- Total CO_2	%
LTH2O	- Total H_2O	%

Flow rates between nodes

CO2	(lb-moles)/min
H2O	(lb-moles)/min
Total	(lb-moles)/min

Rate of adsorption

CO2	(lb-moles)/min
H2O	(lb-moles)/min
Total	(lb-moles)/min

Pressures at the nodes and at inlet and outlet

CO2	mm Hg
H2O	mm Hg
Total	mm Hg

Temperatures

Gas	°F
Bed	°F

The following system variables vs time are also printer plotted at the end of each run:

PCTL	PHOUT	TG(out) - outlet process gas temperature
LTH2O	PCOUT	
LTCO2	TCOUT	

PROGRAM SOURCE LISTINGS

The source listings of each program module shown in the computer printout are included in this section, with the exception of subroutines BEGIN, LOAD, PPLOT, and PACK which are listed in "Digital Computer Program for Desiccant Humidity Control System" date 21 July 1971.

PERFORMANCE MATCHING

A sample case has been processed to simulate cycle 16 of Run Series III of the large scale tests and is included on pages D-22 through D-57.

The computer program utilizes eleven constants to describe the reaction kinetics at a given temperature. Three of these are the basic capacities associated with each kind of adsorption site while the remaining eight are the forward and reverse reaction rate coefficients associated with each of the four kinetic reactions. These constants can be determined experimentally using thermogravimetric equipment. Alternatively, the eleven constants can be manipulated to match large scale test performance. In this case the basic rate data determined for an earlier material preparation was used as a point of departure and the individual rates then adjusted to match the large scale test results. The capacities associated with each of the basic adsorption sites were scaled on the basis of the quantity of coating used in the preparation. The forward and reverse rate coefficients were adjusted to fit the experimental breakthrough curves and to provide the observed interactions between water and CO_2 capacity. It was necessary to increase all of the forward rate coefficients to produce correlation with the test data. CO_2 breakthrough curve is quite fast and therefore simulation consists simply of achieving the correct cyclic capacity. The water adsorption curve does not completely breakthrough and requires curve fitting at the experimental valve of cyclic capacity. The water breakthrough curves for cycle 16 of Run Series III and the results of the sample printout of the computer simulation are shown in figure D-1. It is evident from figure D-1 that the revised rate coefficients permit a satisfactory fit of the test data.

HS-C LARGE SCALE TESTS
H_2O ADSORPTION CURVE
CYCLE - 16 - SERIES III

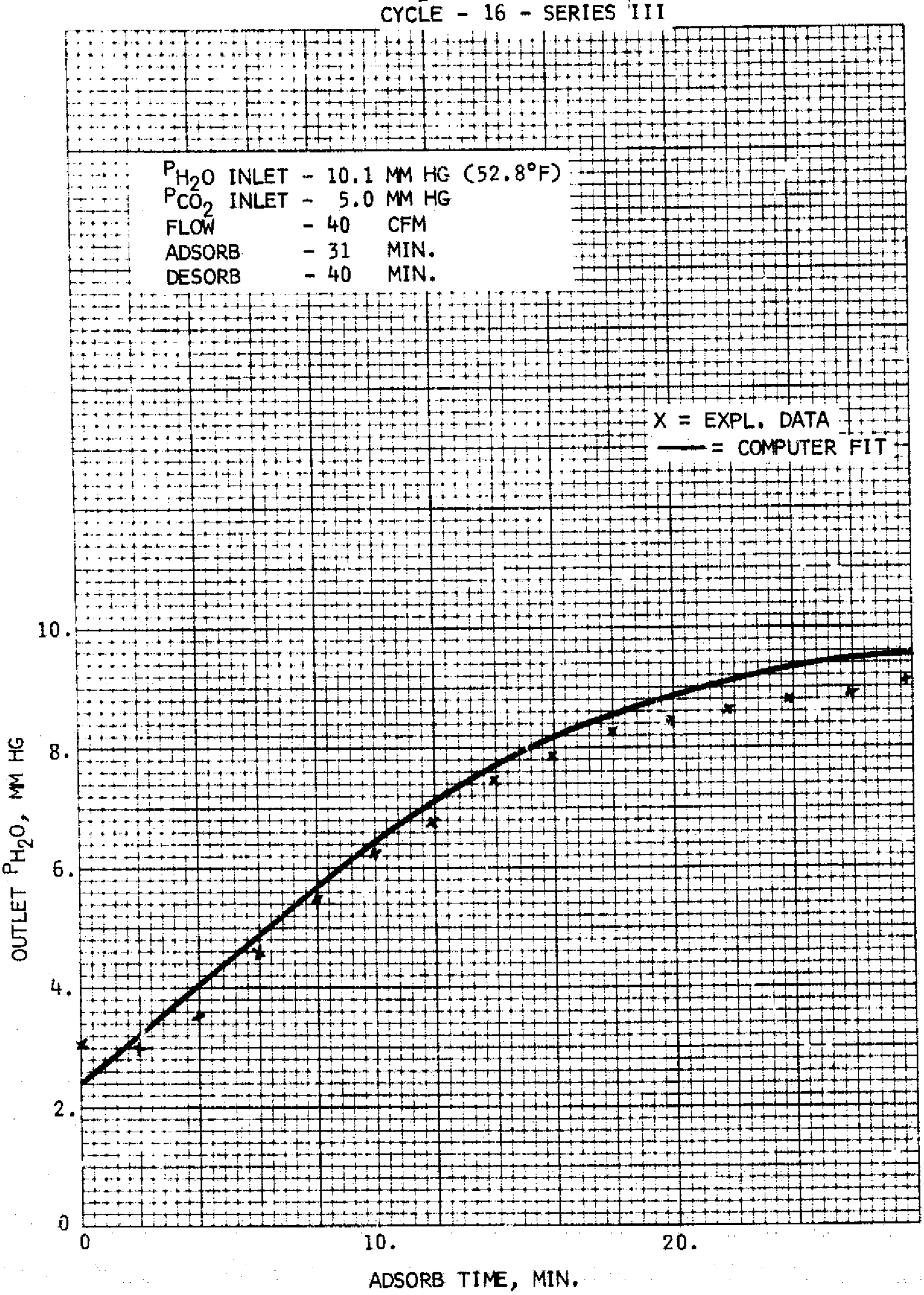


FIGURE D-1

The computer was then used to prepare graphs of performance similar to the experimentally derived figures 13, 14, and 15 of the main body of this report. These are presented as figures D-2, D-3 and D-4. Comparison with the experimental data shows similar trends, indicating a satisfactory computer program. In the case of capacity as a function of flow rate, it must be pointed out that the computer run is for a bed of half the size of the comparative test data. Therefore it is to be expected that the curve will be foreshortened along the flow axis.

HS-C LARGE SCALE PARAMETRIC TESTS
EFFECT ON INLET HUMIDITY ON CYCLIC CAPACITY

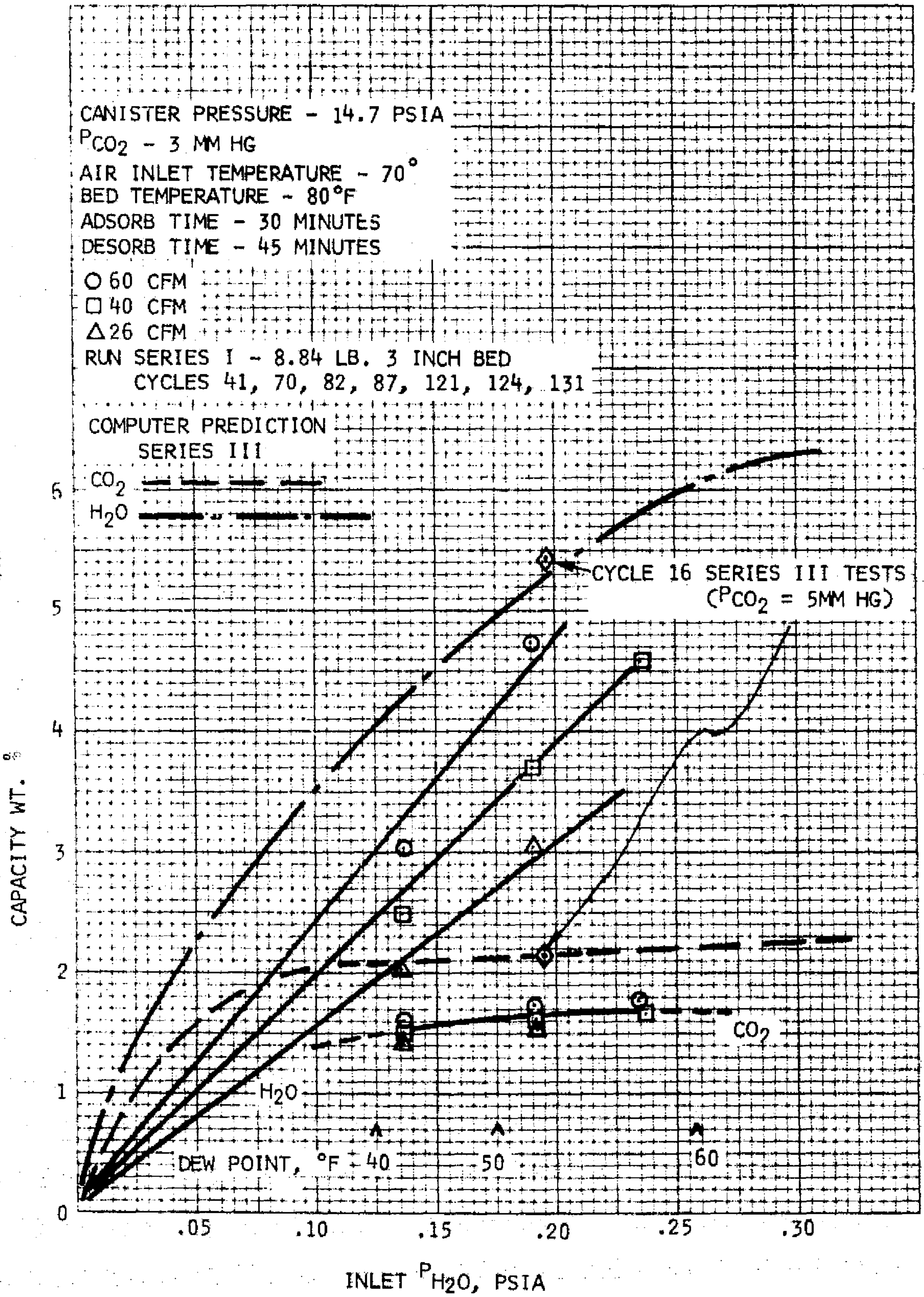


FIGURE D-2

HS-C LARGE SCALE PARAMETRIC TESTS
EFFECT OF PARTIAL PRESSURE OF CO_2
ON CYCLIC CAPACITY

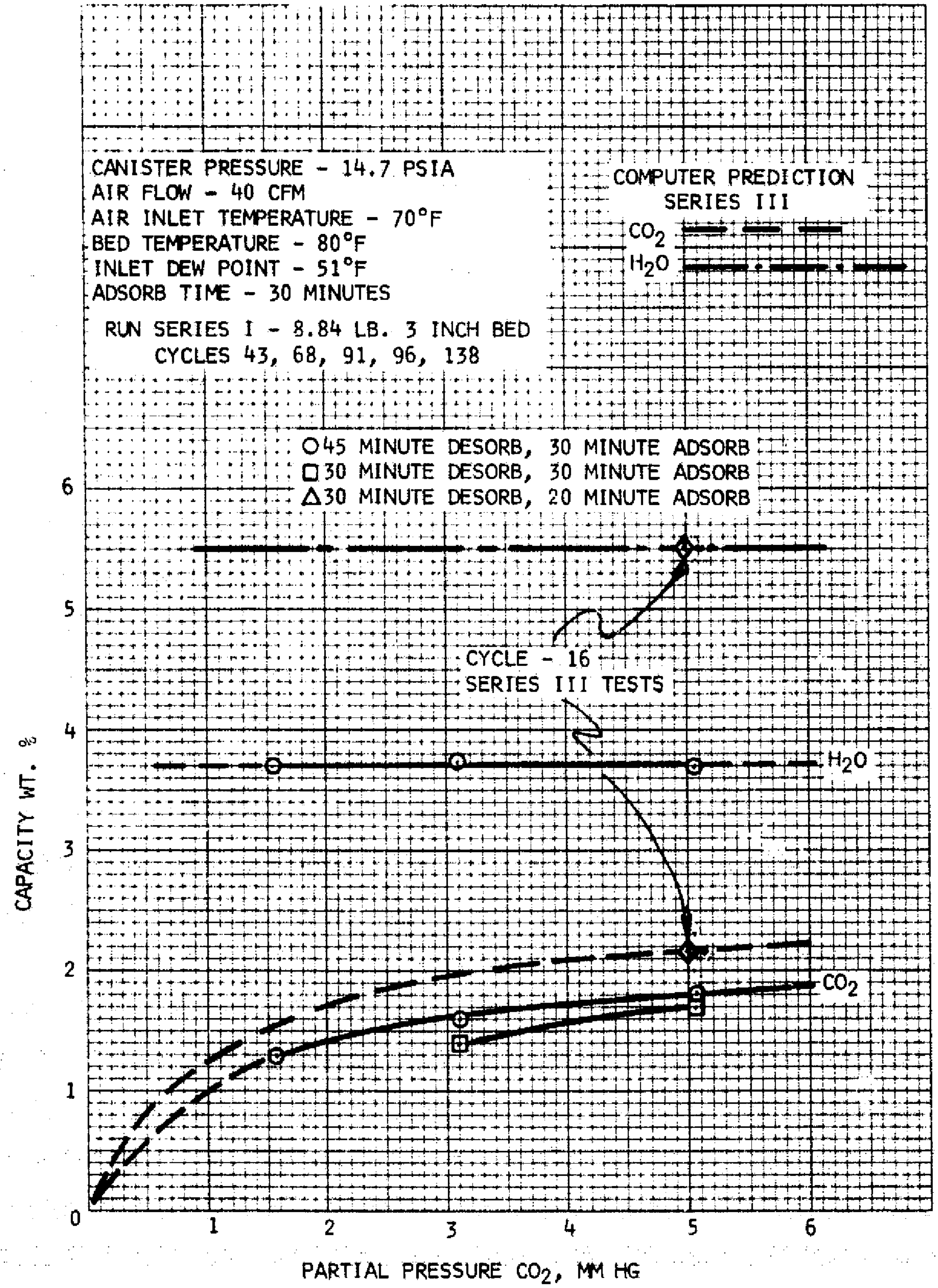


FIGURE D-3

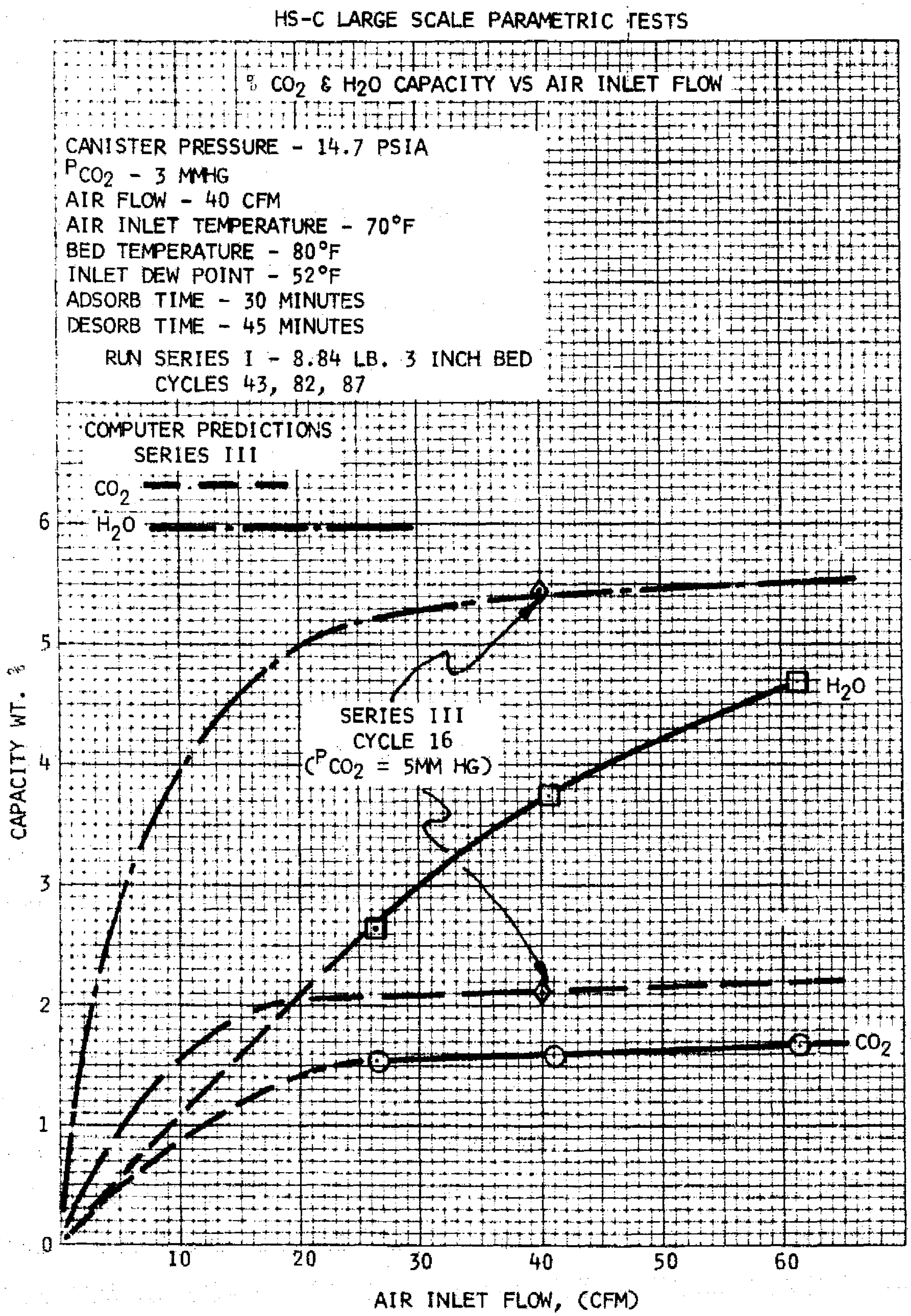

HS-C LARGE SCALE PARAMETRIC TESTS
% CO_2 & H_2O CAPACITY VS AIR INLET FLOW
CANISTER PRESSURE - 14.7 PSIA
P_{CO_2} - 3 MMHG
AIR FLOW - 40 CFM
AIR INLET TEMPERATURE - 70°F
BED TEMPERATURE - 80°F
INLET DEW POINT - 52°F
ADSORB TIME - 30 MINUTES
DESORB TIME - 45 MINUTES
RUN SERIES I - 8.84 LB. 3 INCH BED
CYCLES 43, 82, 87
COMPUTER PREDICTIONS
SERIES III
CO_2
H_2O
SERIES III
CYCLE 16
(P_{CO_2} = 5MM HG)
H_2O
CO_2
CAPACITY WT. %
AIR INLET FLOW, (CFM)

FIGURE D-4

PROGRAM FLOW CHARTS

Figure D-5 illustrates a general flow chart of the program.

A complete set of "Auto Flow" charts is included in this appendix following the sample case printout.

PROGRAM SYMBOL DEFINITIONS

This section relates Fortran names to physical quantities in each of the subroutines.

Main Program

SYMBOL	DEFINITION	UNITS
ADSORB	Adsorption cycle time	(min)
APCO2	Total loading of CO_2/node	(%)
APH2O	Total loading of H_2O/node	(%)
DCO2	CO_2 adsorption/desorption rate/node	(lb-mole/min)
DESORB	Desorption cycle time	(min)
DH2O	H_2O adsorption/desorption rate/node	(lb-mole/min)
DIFF	Difference between present average coolant outlet temperature and past average coolant outlet temperature	(°F)
DMC	Nodal CO_2 inlet flow rate	(lb mole/min)
DMCO	CO_2 flow rate out of each node	(lb mole/min)
DMH	Nodal H_2O inlet flow rate	(lb mole/min)
DMHO	H_2O flow rate out of each node	(lb mole/min)
DT	Computing time interval	(min)
DTP	Computing time interval for subroutine PVAC	(min)
EFFC	CO_2 removal efficiency	(%)
EFFH	H_2O removal efficiency	(%)

GENERAL FLOW CHART

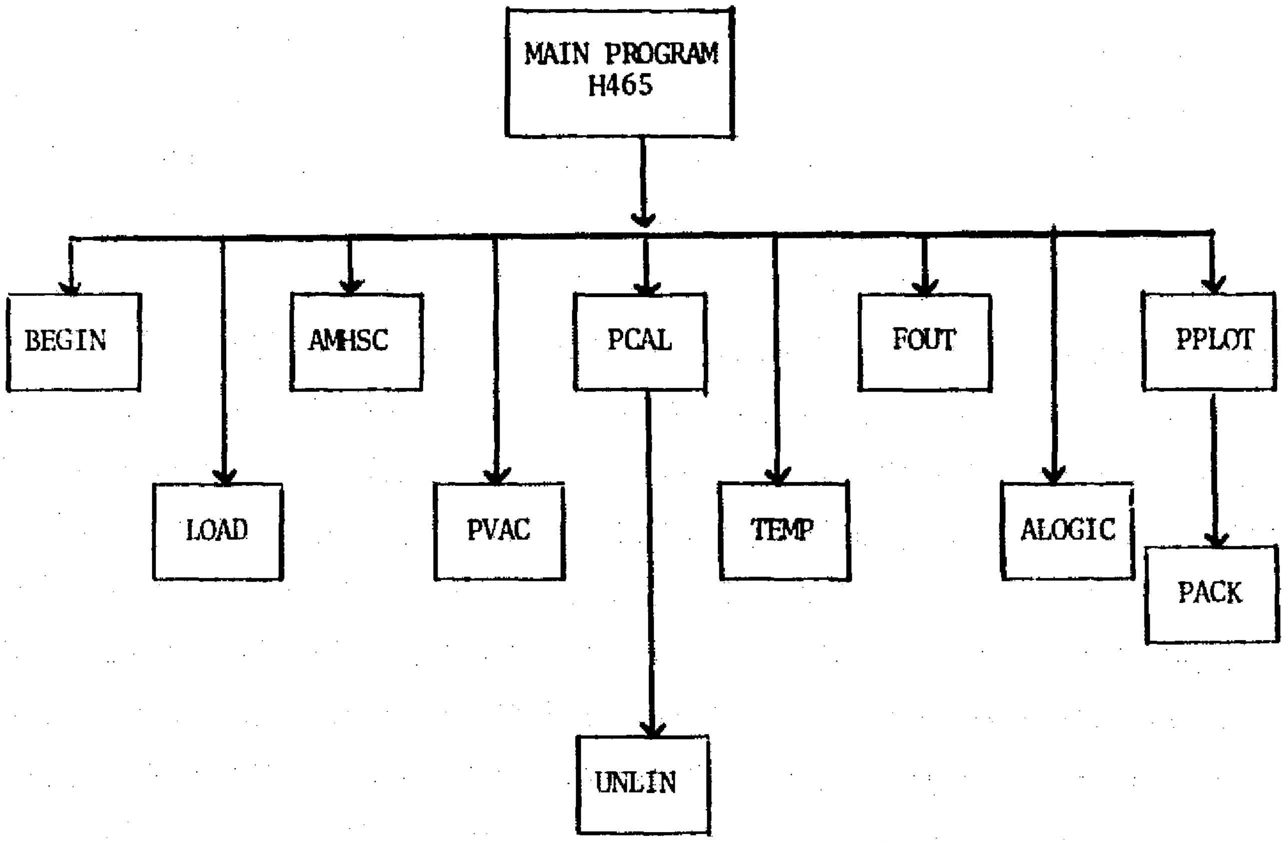


FIGURE D-5

SYMBOL	DEFINITION	UNITS
FN	Number of nodes	
I	nodal index	
ICXC	Initial loading of CO_2 on X sites	(%)
ICYH	Initial loading of H_2O on Y sites	(%)
ICYHC	Initial loading of CO_2 on YH2O sites	(%)
ICZC	Initial loading of H_2O on Z sites	(%)
IDES	Indicator used for system desorption	
ISOT	Indicator used to operate system isothermally or nonisothermally	
IND	Indicator used to specify whether system is adsorbing or desorbing	
JIND	Indicator from subroutine ALOGIC specifying whether the program is in its 1st pass, or whether on adsorb/desorb or desorb/adsorb switch has occurred	
KX	Forward rate coefficient for CO_2 on X sites	
KXR	Reverse rate coefficient for CO_2 on X sites	
KY	Forward rate coefficient for H_2O on Y sites	
KYH	Forward rate coefficient for CO_2 on YH2O sites	
KYHR	Reverse rate coefficient for CO_2 on YH_2O sites	
KYR	Reverse rate coefficient for H_2O on Y sites	
KZ	Forward rate coefficient for H_2O on Z sites	

SYMBOL	DEFINITION	UNITS
KZR	Reverse rate coefficient for H_2O on Z sites	
LTCO2	Percent loading of CO_2 on bed	(%)
LTH2O	Percent loading of H_2O on bed	(%)
LXCO2	Loading of CO_2 on X sites	(lb/lb)
LYH2O	Loading of H_2O on Y sites	(lb/lb)
LYHC	Loading of CO_2 on YH_2O sites	(lb/lb)
LZH2	Loading of H_2O on Z sites	(lb/lb)
MCO2	Molecular weight of CO_2	(lb/lb mole)
MH2O	Molecular weight of H_2O	(lb/lb mole)
MTCO2	Total mass of CO_2 on bed	(lb)
MTH2O	Total mass of H_2O on bed	(lb)
MZ	Bed weight/node	(lb)
MZT	Bed weight	(lb)
N	Number of nodes	
NPLOT	Indicator use to obtain printer plots	
NPRINT	Indicator used to print system output	
PAIR	Total pressure of process gas	(mmHg)
PCO	Bed outlet CO_2 partial pressure	(mmHg)
PCOUT	Nodal outlet partial pressure of CO_2	(mmHg)
PCO2	Nodal inlet partial pressure of CO_2	(mmHg)
PCTL	Total percent loading on bed	(%)
PHO	Bed outlet H_2O partial pressure	(mmHg)
PHOUT	Nodal outlet partial pressure of H_2O	(mmHg)

SYMBOL	DEFINITION	UNITS
PH2O	Nodal inlet partial pressure of H_2O	(mmHg)
PICO2	Bed inlet partial pressure of CO_2	(mmHg)
PIH2O	Bed inlet partial pressure of H_2O	(mmHg)
PIN	Bed inlet total pressure during vacuum desorption	(mmHg)
POUT	Bed outlet total pressure during vacuum desorption	(mmHg)
Q	Process volumetric flow rate	(ft^3/min)
R	Gas constant	(555 ft^3-mmHg/°R-lb mole)
TB	Bed nodal temperature	(°R)
TCIN	Heat exchanger coolant inlet temperature	(°R)
TCOUT	Average coolant outlet temperature	(°R)
TCOUTL	Past value of average coolant outlet temperature	(°R)
TG	Process gas nodal temperature	(°R)
TGI	Process gas inlet temperature	(°R)
TIME	Elapsed transient time	(min)
TMAX	Maximum time duration of transient	(min)
WAIR	Mass flow rate of process gas	(lb/min)
WCTOT	Coolant mass flow rate	(lb/min)
XCO2	Loading of CO_2/node on X sites	(lb-mole/lb_{bed})
XOL	Ultimate loading capacity of CO_2 on X sites	(%)
YHOCO	Loading of CO_2/node on YH_2O sites	(lb mole/lb_{bed})
YH2O	YH2O sites available for CO_2 adsorption which have absorbed H_2O	(lb mole/lb)

SYBMOL	DESCRIPTION	UNITS
YOL	Ultimate loading capacity of H_2O on Y sites	(%)
ZOL	Ultimate loading capacity of H_2O on Z sites	(%)

Subroutine TEMP

SYMBOL	DESCRIPTION	UNITS
AAMB	Heat transfer area between heat exchanger and ambient/node	(ft^2)
AAMBT	Total heat transfer area between heat exchanger and ambient	(ft^2)
AB	Bed cross sectional area	(ft^2)
ABHX	Heat transfer area between bed and heat exchanger node	(ft^2)
ABHXT	Total heat transfer area between bed and heat exchanger	(ft^2)
ACHX	Total heat exchanger heat transfer surface	(ft^2)
AHX	Heat exchanger cross sectional area	(ft^2)
CPBED	Bed specific heat	(BTU/lb-°F)
CPC	Specific heat of coolant flow	(BTU/lb-°F
CPHX	Heat exchanger specific heat	(BTU/lb-°F
DELL	Bed length of each node	(ft)
DMCO	CO_2 flow rate out of each node	(lb mole/min)
DMHO	H_2O flow rate out each node	(lb mole/min)
DT	Subroutine computing time interval	(min)
HAMB	Heat transfer coefficient between heat exchanger external surface and ambient	(BTU/ft^2-min-°F

SYMBOL	DEFINITION	UNITS
HB	Heat transfer coefficient between process gas and bed	(BTU/ft^2-min-°F
HXX	Heat transfer coefficient between coolant air and heat exchanger surface	(BTU/ft^2-min-°F
I	Nodal index	
JIND	Indicator specifying whether the program is in its 1st pass or not	
KB	Bed axial conductance	(BTU/min-ft-°F)
KHX	Heat exchanger metal thermal conductivity	(BTU/min-ft-°F
K1	Total process gas (diluent + CO_2 + H_2O) mass flow rate	(lb/min)
K11	Absolute value of total process gas mass flow rate	(lb/min)
K3	Effective heat transfer coefficient for bed axial conductance	(BTU/min-°F
K4	Effective heat transfer coefficient for heat exchanger axial conductance	(BTU/min-°F
LB	Bed length	(ft)
MCB	Heat capacity of bed/node	(BTU/°F
MCHX	Heat capacity of heat exchanger/node	(BTU/°F
N	Number of nodes	
QR	Heat of adsorption	(BTU/min)
Q1	Heat transfer rate between process gas and bed	(BTU/min)
Q2	Heat transfer rate between heat exchanger and bed	(BTU/min)
Q3	Axial heat transfer rate into bed node	(BTU/min)
Q4	Axial heat transfer rate out of bed node	(BTU/min)

C-3

SYMBOL	DESCRIPTION	UNITS
Q5	Heat transfer rate between coolant and heat exchanger	(BTU/min)
Q6	Heat transfer rate between ambient and heat exchanger	(BTU/min)
Q7	Axial heat transfer rate into heat exchanger node	(BTU/min)
Q8	Axial heat transfer rate out of heat exchanger node	(BTU/min)
TAMB	Ambient temperature	(°R)
TB	Bed nodal temperature	(°R)
TCIN	Coolant inlet temperature	(°R)
TCOUT	Coolant nodal outlet temperature	(°R)
TGI	Process gas inlet temperature	(°R)
TG	Process gas nodal temperature	(°R)
THX	Heat exchanger nodal temperature	(°R)
TIME	Elapsed transient time	(min)
TOUT	Average coolant outlet temperature	(°R)
UAMB	Heat transfer coefficient between ambient and heat exchanger	(BTU/ft^2-min-°F)
UBHX	Heat transfer coefficient between heat exchanger and bed	(BTU/ft^2-min-°F)
WAIR	Process gas mass flow rate	(lb/min)
WBED	Bed weight	(lb)
WC	Coolant mass flow rate/node	(lb/min)
WCO2	CO_2 mass flow rate	(lb/min)
WCTOT	Coolant mass flow rate	(lb/min)

SYMBOL	DESCRIPTION	UNITS
WHX	Heat exchanger core weight	(lb)
WH2O	H_2O mass flow rate	(lb/min)

Subroutine AMHSC

SYMBOL	DESCRIPTION	UNITS
DCO2	CO_2 adsorption/desorption rate/node	(lb-mole/min)
DH2O	H_2O adsorption/desorption rate/node	(lb-mole/min)
DMC	Nodal CO_2 inlet flow rate	(lb mole/min)
DMH	Nodal H_2O inlet flow rate	(lb mole/min)
DT	Subroutine computing time interval	(min)
I	Nodal index	
IDES	Indicator used for system desorption	
IND	Indicator used to specify whether system is adsorbing or desorbing	
JIND	Indicator from subroutine ALOGIC defined under Main Program Symbol Definitions	
KX	Forward rate coefficient for CO_2 on X sites	
KXR	Reverse rate coefficient for CO_2 on X sites	
KY	Forward rate coefficient for H_2O on Y sites	
KYH	Forward rate coefficient for CO_2 on YH_2O sites	
KYHR	Reverse rate coefficient for CO_2 on YH_2O sites	
KYR	Reverse rate coefficient for H_2O on Y sites	

SYMBOL	DESCRIPTION	UNITS
KZ	Forward rate coefficient for H_2O on Z sites	
MCO2	Molecular weight of CO_2	(lb/lb mole)
MH2O	Molecular weight of H_2O	(lb/lb mole)
MZT	Nodal bed weight	(lb)
MZ	Bed weight/node	(lb)
N	Number of nodes	
PCAVG	Average nodal CO_2 partial pressure	(mmHg)
PCOUT	Nodal outlet partial pressure of CO_2	(mmHg)
PCO2	Nodal inlet partial pressure of CO_2	(mmHg)
PHAVG	Average nodal H_2O partial pressure	(mmHg)
PHOUT	Nodal outlet partial pressure of H_2O	(mmHg)
PH2O	Nodal inlet partial pressure of H_2O	(mmHg)
TYH2O	Total loading of H_2O/node of Y sites	(lb mole/lb_{bed})
T	Bed nodal temperature	(°R)
XCO2	Loading of CO_2/node on X sites	(lb mole/lb_{bed})
XO	Ultimate loading capacity of CO_2 on X sites	(lb mole/lb_{bed})
XOL	Ultimate loading capacity of CO_2 on X sites	(%)
XR	Adsorption rate of CO_2/node on X sites	(lb mole/min/lb_{bed})
YHCR	Adsorption rate of CO_2/node on YH_2O sites	(lb mole/min/lb_{bed})
YHOCO	Loading of CO_2/node on YH_2O sites, also H_2O/node on these sites	(lb mole/lb_{bed})
YH2O	Loading of H_2O/node on Y sites with no CO_2 accepted	(lb mole/lb_{bed})

SYMBOL	DESCRIPTION	UNITS
YO	Ultimate loading capacity of H_2O Y sites	(1b mole/$1b_{bed}$)
YOL	Ultimate loading capacity of H_2O on Y sites	(%)
YR	Adsorption rate of H_2O/node on Y sites	(1b mole/min/$1b_{bed}$)
ZH20	Loading of H_2O/node on Z sites	(1b mole/$1b_{bed}$)
ZO	Ultimate loading capacity of H_2O on Z sites	(1b mole/$1b_{bed}$)
ZOL	Ultimate loading capacity of H_2O on Z sites	(%)
ZR	Adsorption rate of H_2O/node on Z sites	(1b mole/min/$1b_{bed}$)

Subroutine FOUT

SYMBOL	DEFINITION	UNITS
AMTOT	Total constituent loading on bed	(1b)
DMH	Constituent inlet flow rate	(1b mole/min)
DT	Subroutine computing time interval	(min)
EFF	Removal efficiency of constituent	(%)
FCT2	Mass of constituent passed through bed during one computing time interval	(1b)
HCOTOT	Total mass of CO_2 passed through bed at any time	(1b)
H2OTOT	Total mass of H_2O passed through bed at any time	(1b)
I	Nodal index	
IND	Indicator used to specify whether system is adsorbing or desorbing	

SYMBOL	DESCRIPTION	UNITS
LTOT	Total constituent loading for each node	(%)
MOLWT	Constituent molecular weight	(lb mole/lb)
MZ	Bed weight per node	(lb)
MZT	Total bed weight	(lb)
N	Number of nodes	
PCM1	Loading at site 1	(%)
PCM2	Loading at site 2	(%)
PCTL	Total constituent bed loading	(%)
TIME	Total elapsed time	(min)
X1	Constituent nodal loading at site 1	(lb mole/lb_{bed})
X2	Constituent nodal loading at site 2	(lb mole/lb_{bed})

Subroutine PVAC

SYMBOL	DEFINITION	UNITS
DCO2	CO_2 adsorption rate/node	(lb mole/min)
DELW	Apparent laminar flow resistance	
DH2O	H_2O adsorption rate/node	(lb mole/min)
D1A	Apparent bed restriction diameter	(inches)
DMC	CO_2 flow rate out front end of bed	(lb mole/min)
DMCO	CO_2 flow rate out of each node	(lb mole/min)
DMH	H_2O flow rate out front end of bed	(lb mole/min)
DMHO	H_2O flow rate out of each node	(lb mole/min)
DMI	Total flow rate out of front end of bed	(lb mole/min)
DMO	Total nodal outlet flow rate	(lb mole/min)

SYMBOL	DEFINITION	UNITS
DT	Subroutine computing time interval	(min)
I	Nodal index	
JIND	Indicator from subroutine ALOGIC defined under Main Program Symbol Definitions	
L	Node bed length	(inches)
N	Number of nodes	
PCOUT	CO_2 partial pressure out of bed	(mmHg)
PCO2	Nodal average CO_2 partial pressure	(mmHg)
PHOUT	H_2O partial pressure out of bed	(mmHg)
PH20	Nodal average H_2O partial pressure	(mmHg)
PIN	Bed inlet pressure	(mmHg)
POUT	Bed outlet pressure	(mmHg)
Pt	Nodal total pressure	(mmHg)
PTA	Average total pressure	(mmHg)
R	Gas constant	(ft^3-mmHg/°F-lb mole)
TG	Nodal process gas temperature	(°R)
VB	Bed void volume	(ft^3)
VNODE	Nodal void volume	(ft^3)
XLEN	Bed length	(ft)
XMU	Absolute viscosity	(lb-sec/in^2)

Subroutine PCAL

SYMBOL	DEFINITION	UNITS
DAD	Constituent adsorption rate/node	(lb mole/min)

25

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CYCLE 16 SERIES III NOMINAL TEST CONDITIONS

INPUT

DT	0.751250E-02	TMAX	146.000	PRINT	1024.00	PLOT	1.00000	FN	5.00000	IND	0.0		
IDES	0.0	ISOT	0.0	XJ	5.00000	ICXC	0.0	ICYH	0.0	ICZC	0.0		
ICYHC	0.0	PIH2O	10.1000	PICO2	5.00000	XOL	2.45000	YOL	8.30000	ZOL	4.15000		
KX	0.140000	KXY	0.100000E 00	KY	0.150000E-01	KYR	0.750000E-01	KYH	0.565000E-03	KYHP	0.128000		
KZ	0.500000E-02	KZP	0.200000E-01	MZT	4.00000	PAIR	755.000	Q	40.0000	TCIN	531.000		
TGI	530.000	PIN	0.100000E-01	POUT	0.100000E-01	ABSORB	51.0000	DESORB	40.0000	VB	4.90000		
XMO	0.350000E-08	DIA	0.250000E-01	WLTOT	1.00000	CPC	0.240000	LB	0.125000	ABHXT	1.00000		
AAMBT	1.00000	WHX	5.00000	WBED	4.00000	CPHX	0.202000	CPBED	0.160000	AB	1.00000		
AHX	1.00000	KB	0.0	KHX	0.0	TAMB	70.0000	HAMB	0.100000E-01	NPT1	3.00000		
NPT2	3.00000	PRLAST	256.000	A	196.000	EPS	0.400000						

Hamilton Standard

OUTPUT

TIME	0.0	PCTI	0.0	TCOUT	531.000			EFFH	100.000	EFFC	100.000
LTH2O	0.0	LTCO2	0.0	LYH2O	0.0	LZH2	0.0	LXCO2	0.0	LYHC	0.0

WT PCT ABSORBED BY NODES

LXCO2	0.0	0.0	0.0	0.0	0.0
LYH2O	0.0	0.0	0.0	0.0	0.0

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67995E-03	0.0	0.0	0.0	0.0	0.0
H2O	0.13734E-02	0.0	0.0	0.0	0.0	0.0
TOTAL	0.20534E-02	0.0	0.0	0.0	0.0	0.0

RATE OF ABSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.0	0.0	0.0	0.0	0.0
H2O	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	0.0	0.0	0.0	0.0	0.0	0.0
H2O	10.100	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	15.100	0.0	0.0	0.0	0.0	0.0	0.0

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

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Hamilton Standard

TIME	8.00000	PCTL	6.00436	TCOUT	531.000			EFFH	43.6253	EFFC	36.0531
LTH2O	3.84729	LTCO2	2.15707	LYH2O	3.07446	LZH2	0.752431	LXCO2	2.09417	LYHC	0.42933E-01

WT PCT ADSORBED BY NODES

LXCO2	2.2162	2.1877	2.1577	2.1272	2.0946
LYH2O	5.5327	4.6686	3.7985	2.9799	2.2568

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67993E-03	0.67591E-03	0.67144E-03	0.66629E-03	0.66007E-03	0.65212E-03
H2O	0.13734E-02	0.12152E-02	0.10359E-02	0.84964E-03	0.67154E-03	0.51322E-03
TOTAL	0.20534E-02	0.18911E-02	0.17073E-02	0.15159E-02	0.13316E-02	0.11653E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.40166E-05	0.44697E-05	0.51450E-05	0.62252E-05	0.79526E-05
H2O	0.15621E-03	0.17937E-03	0.18623E-03	0.17810E-03	0.15832E-03
TOTAL	0.16223E-03	0.18384E-03	0.19137E-03	0.18433E-03	0.16627E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9852	4.9539	4.9185	4.8766	4.8242	4.7955
H2O	10.100	9.5176	8.2751	6.9299	5.5899	4.3529	3.7741
TOTAL	15.100	14.503	13.229	11.848	10.466	9.1771	8.5696

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	16.0000	PCTL	8.45751	TCOUT	531.000			EFFH	23.0896	EFFC	19.0803
LTH2O	5.17437	LTCO2	2.28315	LYH2O	4.67070	LZH2	1.50357	LXCO2	2.12091	LYHC	0.162240

WT PCT ADSORBED BY NODES

LXCO2	2.3314	2.3083	2.2838	2.2586	2.2336
LYH2O	7.2414	6.7921	6.2560	5.6361	4.9463

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67993E-03	0.67819E-03	0.67623E-03	0.67413E-03	0.67197E-03	0.66983E-03
H2O	0.13734E-02	0.13195E-02	0.12473E-02	0.11556E-02	0.10451E-02	0.91908E-03
TOTAL	0.20534E-02	0.19977E-02	0.19236E-02	0.18298E-02	0.17170E-02	0.15889E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.17395E-05	0.19538E-05	0.20972E-05	0.21682E-05	0.21402E-05
H2O	0.53928E-04	0.72174E-04	0.91727E-04	0.11057E-03	0.12597E-03
TOTAL	0.55668E-04	0.74128E-04	0.93824E-04	0.11274E-03	0.12811E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9936	4.9800	4.9651	4.9494	4.9336	4.9257
H2O	10.100	9.9015	9.4374	8.8343	8.0900	7.2197	6.7587
TOTAL	15.100	14.895	14.417	13.799	13.039	12.153	11.684

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	24.0000	PCTL	9.68336	TCOUT	531.000			EFFH	15.9565	EFFC	13.1029
LTH2O	7.33153	LTCO2	2.35183	LYH2O	5.26690	LZH2	2.06463	LXCO2	2.12202	LYHC	0.229318

WT PCT ABSORBED BY NODES

LXCO2	2.3833	2.3699	2.3542	2.3360	2.3158
LYH2O	7.8081	7.6653	7.3916	7.0577	6.5549

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67993E-03	0.67916E-03	0.67821E-03	0.67704E-03	0.67557E-03	0.67413E-03
H2O	0.13734E-02	0.13500E-02	0.13183E-02	0.12766E-02	0.12231E-02	0.11558E-02
TOTAL	0.20534E-02	0.20291E-02	0.19965E-02	0.19537E-02	0.18987E-02	0.18299E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.76551E-06	0.95373E-06	0.11640E-05	0.13692E-05	0.15453E-05
H2O	0.23456E-04	0.31654E-04	0.41659E-04	0.53585E-04	0.67241E-04
TOTAL	0.24252E-04	0.32607E-04	0.42823E-04	0.54954E-04	0.68788E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9972	4.9909	4.9831	4.9737	4.9630	4.9573
H2O	10.100	10.014	9.8107	9.5409	9.1905	8.7459	8.4996
TOTAL	15.100	15.011	14.802	14.524	14.164	13.709	13.457

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	31.0078	PCTL	10.2276	TCOUT	531.000			EFFH	12.4640	EFFC	10.2994
LTH2O	7.84291	LTCO2	2.38471	LYH2O	5.45065	LZH2	2.39226	LXCO2	2.12260	LYHC	0.262111

WT PCT ABSORBED BY NODES

LXCO2	2.4030	2.3957	2.3867	2.3757	2.3625
LYH2O	8.1651	8.0361	7.8782	7.6853	7.4499

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.35317E-02	-0.18894E-02	-0.14185E-02	0.15953E-02	0.20825E-02	0.33535E-02
H2O	-0.71022E-02	-0.37503E-02	-0.27784E-02	0.31247E-02	0.40101E-02	0.63044E-02
TOTAL	-0.10634E-01	-0.56397E-02	-0.41968E-02	0.47200E-02	0.60926E-02	0.96579E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.35406E-06	0.46947E-06	0.60360E-06	0.75544E-06	0.94129E-06
H2O	0.13300E-04	0.17241E-04	0.22496E-04	0.28972E-04	0.36877E-04
TOTAL	0.13354E-04	0.17710E-04	0.23100E-04	0.29728E-04	0.37818E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.33212E-02	2.9517	3.9333	4.1677	3.9429	2.9409	0.34723E-02
H2O	0.66788E-02	5.9357	7.7891	8.1631	7.6012	5.5288	0.65277E-02
TOTAL	0.10000E-01	8.8874	11.722	12.331	11.544	8.4697	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	32.0000	PCTL	9.70052	TCOUT	531.000	EFFH	11.5399	EFFC	9.48945

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Hamilton Standard

LTH2O 7.51573 LTCO2 2.18479 LYH2O 5.15303 LZH2 2.36270 LXCO2 1.95013 LYHC 0.234557

WT PCT ABSORBED BY NODES

LXCO2	2.1958	2.1968	2.1912	2.1796	2.1606
LYH2O	7.6079	7.7066	7.5629	7.3737	7.1277

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.67175E-04	-0.50980E-04	-0.16099E-04	0.18223E-04	0.52633E-04	0.87914E-04
H2O	-0.36382E-03	-0.20841E-03	-0.64637E-04	0.73184E-04	0.20936E-03	0.34980E-03
TOTAL	-0.45099E-03	-0.25939E-03	-0.80736E-04	0.91412E-04	0.26200E-03	0.43771E-03

RATE OF ABSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.36043E-04	-0.34678E-04	-0.34106E-04	-0.34198E-04	-0.35123E-04
H2O	-0.15516E-03	-0.14348E-03	-0.13751E-03	-0.13589E-03	-0.14021E-03
TOTAL	-0.19122E-03	-0.17815E-03	-0.17161E-03	-0.17009E-03	-0.17533E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.19330E-02	0.39304	0.50156	0.53700	0.50880	0.40234	0.20084E-02
H2O	0.80670E-02	1.6405	2.0506	2.1563	2.0241	1.6010	0.79916E-02
TOTAL	0.10000E-01	2.0335	2.5521	2.6933	2.5329	2.0033	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

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 TIME    71.0078     PCTL     3.12057     TCOUT   531.000                                EFFH     1.80293      EFFC     1.35293
 LTH2O   2.82224     LTCO2  0.298336      LYH2O   1.40166       LZH2      1.42058        LXCO2  0.294793       LYHC   0.354279E-02

WT PCT ADSORBED BY NODES
 LXCO2                     0.25780       0.31510       0.33424       0.31991       0.26463
 LYH2O                      2.7250        2.9716        3.0067        2.8772        2.5307

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2               0.67992E-03  0.68161E-03  0.68440E-03  0.68631E-03  0.68818E-03  0.68987E-03
 H2O               0.13734E-02  0.13942E-02  0.14241E-02  0.14442E-02  0.14636E-02  0.14823E-02
 TOTAL             0.20534E-02  0.20758E-02  0.21085E-02  0.21305E-02  0.21518E-02  0.21722E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                     -0.16903E-05 -0.27808E-05 -0.19112E-05 -0.18687E-05 -0.16939E-05
 H2O                     -0.20730E-04 -0.29949E-04 -0.20024E-04 -0.19476E-04 -0.18716E-04
 TOTAL                   -0.22420E-04 -0.32730E-04 -0.21935E-04 -0.21344E-04 -0.20410E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2       5.0000        0.577416E-01  0.76295E-01  0.82948E-01  0.78112E-01  0.60228E-01    5.0731
 H2O       10.100        0.65382       0.82173      0.86643      0.81316      0.64054        10.901
 TOTAL     15.100        0.71157       0.89802      0.94938      0.89128      0.70076        15.974

TEMPERATURES (DEG F)
 GAS                       530.00        530.00        530.00        530.00        530.00
 BED                       531.00        531.00        531.00        531.00        531.00


 TIME    72.0000     PCTL     4.15284     TCOUT   531.000                                EFFH     5.06008      EFFC     3.82315
 LTH2O   3.28018     LTCO2  0.872661      LYH2O   1.81631       LZH2      1.46387        LXCO2  0.863784       LYHC   0.867721E-02

WT PCT ADSORBED BY NODES
 LXCO2                      1.1594        1.0133       0.87279       0.73563       0.58219
 LYH2O                      3.5530        3.5298        3.3981        3.1655        2.7544

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2               0.67992E-03  0.55802E-03  0.44782E-03  0.35198E-03  0.27120E-03  0.20395E-03
 H2O               0.13734E-02  0.10318E-02  0.79064E-03  0.61572E-03  0.48465E-03  0.37951E-03
 TOTAL             0.20534E-02  0.15898E-02  0.12385E-02  0.96770E-03  0.75586E-03  0.58347E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                      0.12190E-03  0.11020E-03  0.95838E-04  0.80781E-04  0.67246E-04
 H2O                      0.34167E-03  0.24114E-03  0.17492E-03  0.13106E-03  0.10515E-03
 TOTAL                    0.46357E-03  0.35134E-03  0.27076E-03  0.21184E-03  0.17240E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2       5.0000         4.5497        3.6930        2.9339        2.2843        1.7406        1.4998
 H2O       10.100         8.8421        6.6971        5.1669        4.0421        3.1741        2.7908
 TOTAL     15.100         13.392        10.390        8.1008        6.3264        4.9148        4.2907

TEMPERATURES (DEG F)
 GAS                       530.00        530.00        530.00        530.00        530.00
 BED                       531.00        531.00        531.00        531.00        531.00
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TIME	74.0000	PCTL	5.79582	TCOUT	531.000			EFFH	9.06699	EFFC	5.86374
LTH2O	4.12525	LTCO2	1.67058	LYH2O	2.56551	LZH2	1.55974	LXCO2	1.64307	LYHC	0.275[illegible]44E-01

WT PCT ADSORBED BY NODES

LXCO2	1.9215	1.8193	1.6956	1.5483	1.3681
LYH2O	4.8623	4.5343	4.1786	3.7831	3.2680

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.64556E-03	0.60321E-03	0.55270E-03	0.49459E-03	0.42969E-03
H2O	0.13734E-02	0.11279E-02	0.92330E-03	0.75343E-03	0.61190E-03	0.49005E-03
TOTAL	0.20534E-02	0.17735E-02	0.15265E-02	0.13061E-02	0.11065E-02	0.91974E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.34365E-04	0.42354E-04	0.50508E-04	0.58108E-04	0.64902E-04
H2O	0.24555E-03	0.20459E-03	0.16988E-03	0.14153E-03	0.12184E-03
TOTAL	0.27992E-03	0.24695E-03	0.22039E-03	0.19964E-03	0.18675E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.8730	4.5896	4.2468	3.8462	3.3929	3.1598
H2O	10.100	9.1960	7.5391	6.1615	5.0164	4.0483	3.6037
TOTAL	15.100	14.069	12.129	10.408	8.8626	7.4411	6.7635

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	76.0000	PCTL	6.89775	TCOUT	531.000			EFFH	10.3308	EFFC	7.86111
LTH2O	4.86825	LTCO2	2.02950	LYH2O	3.20385	LZH2	1.66440	LXCO2	1.97598	LYHC	0.535170E-01

WT PCT ADSORBED BY NODES

LXCO2	2.1396	2.0979	2.0450	1.9776	1.8874
LYH2O	5.8007	5.3680	4.9110	4.4229	3.8387

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.66922E-03	0.65538E-03	0.63742E-03	0.61413E-03	0.58386E-03
H2O	0.13734E-02	0.11978E-02	0.10314E-02	0.87695E-03	0.73572E-03	0.60532E-03
TOTAL	0.20534E-02	0.18670E-02	0.16868E-02	0.15144E-02	0.13498E-02	0.11892E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.10706E-04	0.13837E-04	0.17563E-04	0.23292E-04	0.30266E-04
H2O	0.17568E-03	0.16639E-03	0.15443E-03	0.14123E-03	0.13040E-03
TOTAL	0.18639E-03	0.18023E-03	0.17239E-03	0.16452E-03	0.16067E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9605	4.8699	4.7525	4.6001	4.4025	4.2936
H2O	10.100	9.4532	8.1941	7.0136	5.9262	4.9275	4.4514
TOTAL	15.100	14.414	13.064	11.766	10.526	9.3299	8.7449

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	78.0000	PCTL	7.67097	TCOUT	531.000			EFFH	10.3627	EFFC	7.92371
LTH2O	5.50765	LTCO2	2.16333	LYH2O	3.73418	LZH2	1.77347	LXCO2	2.08105	LYHC	0.827314E-01

WT PCT ADSORBED BY NODES

LXCO2	2.2175	2.1952	2.1690	2.1376	2.0974
LYH2O	6.4723	6.0362	5.5599	5.0410	4.4289

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.67511E-03	0.66946E-03	0.66261E-03	0.65404E-03	0.64294E-03
H2O	0.13734E-02	0.12475E-02	0.11159E-02	0.98232E-03	0.84993E-03	0.71930E-03
TOTAL	0.20534E-02	0.19226E-02	0.17854E-02	0.16449E-02	0.15040E-02	0.13622E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.43151E-05	0.56488E-05	0.68517E-05	0.85740E-05	0.11093E-04
H2O	0.12573E-03	0.13158E-03	0.13361E-03	0.13239E-03	0.13063E-03
TOTAL	0.13075E-03	0.13723E-03	0.14046E-03	0.14097E-03	0.14172E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9823	4.9437	4.8976	4.8407	4.7681	4.7280
H2O	10.100	9.6364	8.6884	7.7126	6.7340	5.7667	5.2895
TOTAL	15.100	14.619	13.632	12.610	11.575	10.535	10.018

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	80.0000	PCTL	8.26807	TCOUT	531.000			EFFH	10.0445	EFFC	7.70939
LTH2O	6.04717	LTCO2	2.22090	LYH2O	4.15415	LZH2	1.88303	LXCO2	2.11308	LYHC	0.113814

WT PCT ADSORBED BY NODES

LXCO2	2.2596	2.2421	2.2231	2.2022	2.1775
LYH2O	6.9552	6.5599	6.1112	5.6060	5.0036

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.67676E-03	0.67338E-03	0.66971E-03	0.66560E-03	0.66083E-03
H2O	0.13734E-02	0.12825E-02	0.11802E-02	0.10686E-02	0.95034E-03	0.82647E-03
TOTAL	0.20534E-02	0.19593E-02	0.18535E-02	0.17383E-02	0.16159E-02	0.14873E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.31665E-05	0.33742E-05	0.36720E-05	0.41089E-05	0.47769E-05
H2O	0.90937E-04	0.10235E-03	0.11158E-03	0.11824E-03	0.12387E-03
TOTAL	0.94103E-04	0.10572E-03	0.11525E-03	0.12235E-03	0.12865E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9883	4.9643	4.9383	4.9096	4.8769	4.8595
H2O	10.100	9.7652	9.0537	8.2664	7.4209	6.5303	6.0777
TOTAL	15.100	14.754	14.018	13.205	12.331	11.407	10.937

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	82.0000	PCTL	8.75042	TCOUT	531.000			EFFH	9.66120	EFFC	7.44321
LTH2O	6.44490	LTCO2	2.25552	LYH2O	4.5[illegible]00	LZH2	1.98990	LXCO2	2.11790	LYHC	0.137615

WT PCT ADSORBED BY NODES					
LXCO2	2.2902	2.2741	2.2570	2.2386	2.2177
LYH2O	7.3057	6.9655	6.5658	6.1013	5.5362

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES						
CO2	0.67992E-03	0.67743E-03	0.67485E-03	0.67218E-03	0.66939E-03	0.66644E-03
H2O	0.13734E-02	0.13070E-02	0.12280E-02	0.11370E-02	0.10352E-02	0.92280E-03
TOTAL	0.20534E-02	0.19844E-02	0.19029E-02	0.18092E-02	0.17046E-02	0.15892E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES					
CO2	0.24906E-05	0.25814E-05	0.26772E-05	0.27884E-05	0.29442E-05
H2O	0.66439E-04	0.79009E-04	0.90998E-04	0.10183E-03	0.11237E-03
TOTAL	0.68929E-04	0.81591E-04	0.93676E-04	0.10462E-03	0.11531E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)							
CO2	5.0000	4.9908	4.9722	4.9528	4.9327	4.9116	4.9009
H2O	10.100	9.8554	9.3200	8.6944	7.9848	7.1968	6.7861
TOTAL	15.100	14.846	14.292	13.647	12.918	12.108	11.687

TEMPERATURES (DEG F)					
GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	84.0000	PCTL	9.14384	TCOUT	531.000			EFFH	9.28372	EFFC	7.17684
LTH2O	6.86173	LTCO2	2.28212	LYH2O	4.75999	LZH2	2.09174	LXCO2	2.12015	LYHC	0.161968

WT PCT ADSORBED BY NODES					
LXCO2	2.3149	2.2999	2.2836	2.2661	2.2462
LYH2O	7.5635	7.2784	6.9338	6.5221	6.0109

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES						
CO2	0.67992E-03	0.67787E-03	0.67573E-03	0.67350E-03	0.67120E-03	0.66884E-03
H2O	0.13734E-02	0.13242E-02	0.12632E-02	0.11901E-02	0.11046E-02	0.10061E-02
TOTAL	0.20534E-02	0.20021E-02	0.19390E-02	0.18636E-02	0.17758E-02	0.16749E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES					
CO2	0.20515E-05	0.21454E-05	0.22294E-05	0.22966E-05	0.23596E-05
H2O	0.49271E-04	0.60953E-04	0.73162E-04	0.85471E-04	0.98485E-04
TOTAL	0.51322E-04	0.63099E-04	0.75391E-04	0.87768E-04	0.10085E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)							
CO2	5.0000	4.9925	4.9770	4.9609	4.9443	4.9271	4.9185
H2O	10.100	9.9186	9.5129	9.0193	8.4356	7.7588	7.3986
TOTAL	15.100	14.911	14.490	13.980	13.380	12.686	12.317

TEMPERATURES (DEG F)					
GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	86.0000	PCTL	9.46422	TCOUT	531.000			EFFH	8.92682	EFFC	6.72181
LTH2O	7.15969	LTCO2	2.30453	LYH2O	4.97270	LZH2	2.18720	LXCO2	2.12095	LYHC	0.183576

WT PCT ADSORBED BY NODES

LXCO2	2.3353	2.3214	2.3061	2.2895	2.2704
LYH2O	7.7562	7.5201	7.2285	6.8722	6.4215

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.67823E-03	0.67642E-03	0.67451E-03	0.67250E-03	0.67042E-03
H2O	0.13734E-02	0.13363E-02	0.12890E-02	0.12306E-02	0.11601E-02	0.10759E-02
TOTAL	0.20534E-02	0.20145E-02	0.19655E-02	0.19051E-02	0.18326E-02	0.17463E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.16907E-05	0.18119E-05	0.19162E-05	0.20043E-05	0.20820E-05
H2O	0.37167E-04	0.47233E-04	0.58422E-04	0.70539E-04	0.84158E-04
TOTAL	0.38858E-04	0.49044E-04	0.60338E-04	0.72543E-04	0.86240E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9936	4.9809	4.9672	4.9527	4.9377	4.9331
H2O	10.100	9.9632	9.6525	9.2637	8.7891	8.2199	7.9121
TOTAL	15.100	14.957	14.633	14.231	13.742	13.158	12.842

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	88.0000	PCTL	9.72439	TCOUT	531.000			EFFH	8.59107	EFFC	6.67357
LTH2O	7.40063	LTCO2	2.32376	LYH2O	5.12585	LZH2	2.27478	LXCO2	2.12137	LYHC	0.202395

WT PCT ADSORBED BY NODES

LXCO2	2.3520	2.3395	2.3255	2.3100	2.2919
LYH2O	7.9028	7.7081	7.4635	7.1596	6.7691

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.67854E-03	0.67702E-03	0.67538E-03	0.67362E-03	0.67175E-03
H2O	0.13734E-02	0.13449E-02	0.13080E-02	0.12614E-02	0.12038E-02	0.11331E-02
TOTAL	0.20534E-02	0.20234E-02	0.19850E-02	0.19368E-02	0.18774E-02	0.18048E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.13883E-05	0.15172E-05	0.16432E-05	0.17584E-05	0.18674E-05
H2O	0.28548E-04	0.36893E-04	0.46597E-04	0.57651E-04	0.70668E-04
TOTAL	0.29936E-04	0.38411E-04	0.48240E-04	0.59409E-04	0.72535E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9949	4.9842	4.9726	4.9601	4.9467	4.9399
H2O	10.100	9.9949	9.7541	9.4468	9.0632	8.5910	8.3325
TOTAL	15.100	14.990	14.738	14.419	14.023	13.538	13.272

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	90.0000	PCTL	9.93549	TCOUT	531.000			EFFH	8.27475	EFFC	6.44963
LTH2O	7.59528	LTCO2	2.34021	LYH2O	5.24057	LZH2	2.35477	LXCO2	2.12168	LYHC	0.218535

WT PCT ABSORBED BY NODES

LXCO2	2.3656	2.3546	2.3420	2.3279	2.3111
LYH2O	8.0164	7.8556	7.6512	7.3939	7.0594

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.67880E-03	0.67754E-03	0.67614E-03	0.67462E-03	0.67296E-03
H2O	0.13734E-02	0.13511E-02	0.13220E-02	0.12847E-02	0.12378E-02	0.11791E-02
TOTAL	0.20534E-02	0.20299E-02	0.19996E-02	0.19609E-02	0.19124E-02	0.18521E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.11291E-05	0.12522E-05	0.14002E-05	0.15228E-05	0.16641E-05
H2O	0.22325E-04	0.29114E-04	0.37274E-04	0.46923E-04	0.58697E-04
TOTAL	0.23455E-04	0.30366E-04	0.38675E-04	0.48446E-04	0.60361E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9958	4.9871	4.9773	4.9666	4.9548	4.9487
H2O	10.100	10.318	9.8285	9.5642	9.2744	8.8857	8.6709
TOTAL	15.100	15.014	14.816	14.562	14.241	13.841	13.620

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	92.0000	PCTL	10.1070	TCOUT	531.000			EFFH	7.97630	EFFC	6.23121
LTH2O	7.75288	LTCO2	2.35414	LYH2O	5.32589	LZH2	2.42698	LXCO2	2.12194	LYHC	0.232205

WT PCT ABSORBED BY NODES

LXCO2	2.3765	2.3670	2.3559	2.3432	2.3282
LYH2O	8.1059	7.9726	7.8017	7.5845	7.2996

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.67901E-03	0.67798E-03	0.67680E-03	0.67549E-03	0.67404E-03
H2O	0.13734E-02	0.13557E-02	0.13324E-02	0.13025E-02	0.12643E-02	0.12158E-02
TOTAL	0.20534E-02	0.20347E-02	0.20104E-02	0.19793E-02	0.19398E-02	0.18898E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.91209E-06	0.10316E-05	0.11765E-05	0.13107E-05	0.14512E-05
H2O	0.17761E-04	0.23237E-04	0.29989E-04	0.38194E-04	0.48481E-04
TOTAL	0.18673E-04	0.24269E-04	0.31165E-04	0.39505E-04	0.49932E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9966	4.9895	4.9814	4.9722	4.9620	4.9567
H2O	10.100	10.035	9.8838	9.6879	9.4370	9.1190	8.9406
TOTAL	15.100	15.031	14.873	14.669	14.409	14.080	13.897

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

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 TIME    102.000     PCTL     10.5990     TCOUT   531.000                                 EFFH     6.71402    EFFC     5.29325
 LTH2O   6.20355     LTCO2    2.39546     LYH2O   5.51729        LZH2     2.66626         LXCO2    2.12274    LYHC     0.272719

WT PCT ADSORBED BY NODES
 LXCO2                       2.4057        2.4015        2.3966        2.3905        2.3830
 LYH2O                       8.3578        8.3006        8.2262        8.1304        8.0027

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2                 0.67992E-03  0.67962E-03  0.67926E-03  0.67882E-03  0.67829E-03  0.67764E-03
 H2O                 0.13734E-02  0.13666E-02  0.13577E-02  0.13463E-02  0.13316E-02  0.13125E-02
 TOTAL               0.20534E-02  0.20462E-02  0.20370E-02  0.20251E-02  0.20099E-02  0.19902E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                         0.30128E-06  0.36634E-06  0.44181E-06  0.52943E-06  0.64196E-06
 H2O                         0.68891E-05  0.88536E-05  0.11408E-04  0.14697E-04  0.19070E-04
 TOTAL                       0.71904E-05  0.92199E-05  0.11850E-04  0.15226E-04  0.19712E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2         5.0000        4.9959        4.9964        4.9935        4.9899        4.9856        4.9832
 H2O         10.100        10.075        10.017        9.9422        9.8461        9.7219        9.6520
 TOTAL       15.100        15.074        15.013        14.936        14.836        14.707        14.635

TEMPERATURES (DEG F)
 GAS                         530.00        530.00        530.00        530.00        530.00
 BED                         531.00        531.00        531.00        531.00        531.00


 TIME    102.006     PCTL     10.5992     TCOUT   531.000                                 EFFH     6.71880    EFFC     5.29665
 LTH2O   6.20377     LTCO2    2.39548     LYH2O   5.51736        LZH2     2.68641         LXCO2    2.12274    LYHC     0.272738

WT PCT ADSORBED BY NODES
 LXCO2                       2.4057        2.4016        2.3966        2.3906        2.3830
 LYH2O                       8.3560        8.3007        8.2264        8.1307        8.0030

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2                -0.35372E-02 -0.19882E-02 -0.15376E-02  0.16165E-02  0.21001E-02  0.34422E-02
 H2O                -0.71286E-02 -0.39808E-02 -0.30584E-02  0.32152E-02  0.41446E-02  0.67124E-02
 TOTAL              -0.10666E-01 -0.59690E-02 -0.45960E-02  0.48317E-02  0.62448E-02  0.10155E-01

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                         0.30104E-06  0.36606E-06  0.44151E-06  0.52899E-06  0.64149E-06
 H2O                         0.68846E-05  0.88476E-05  0.11400E-04  0.14687E-04  0.19057E-04
 TOTAL                       0.71856E-05  0.92137E-05  0.11842E-04  0.15216E-04  0.19698E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2     0.33163E-02   2.9518        3.9616        4.2013        3.9605        2.9439        0.33898E-02
 H2O     0.66837E-02   5.9490        7.9221        8.3565        7.8199        5.7408        0.66102E-02
 TOTAL   0.10000E-01   8.9008        11.884        12.558        11.780        8.6848        0.10000E-01

TEMPERATURES (DEG F)
 GAS                         530.00        530.00        530.00        530.00        530.00
 BED                         531.00        531.00        531.00        531.00        531.00

 TIME    104.000     PCTL     9.55779     TCOUT   531.000                                 EFFH     5.70862    EFFC     4.47460
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Hamilton Standard

CR-115568
SVHSER-6640

LTH2O	7.[illegible]4415	LTCO2	2.01364	LYH2O	4.93378	LZH2	2.61036	LXCO2	1.79596	LYHC	[illegible].217561

WT PCT ADSORBED BY NODES

LXCO2	2.0121	2.0230	2.0234	2.0148	1.9949
LYH2O	7.6560	7.6461	7.5911	7.4929	7.3346

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.76982E-04	-0.45150E-04	-0.14598E-04	0.15505E-04	0.45828E-04	0.77210E-04
H2O	-0.34503E-03	-0.19953E-03	-0.63865E-04	0.67833E-04	0.20007E-03	0.33871E-03
TOTAL	-0.42202E-03	-0.24468E-03	-0.78463E-04	0.83338E-04	0.24590E-03	0.41592E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.31701E-04	-0.30381E-04	-0.29918E-04	-0.30150E-04	-0.31250E-04
H2O	-0.14528E-03	-0.13537E-03	-0.13139E-03	-0.13195E-03	-0.13842E-03
TOTAL	-0.17699E-03	-0.16575E-03	-0.16131E-03	-0.16210E-03	-0.16967E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.18241E-02	0.35601	0.45621	0.48628	0.45907	0.36250	0.18552E-02
H2O	0.81756E-02	1.6083	2.0162	2.1276	2.0043	1.5904	0.81437E-02
TOTAL	0.10000E-01	1.9671	2.4724	2.6139	2.4634	1.9528	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	106.000	PCTL	8.69049	TCOUT	531.000			EFFH	4.90273	EFFC	3.82447
LTH2O	6.97525	LTCO2	1.71525	LYH2O	4.43941	LZH2	2.53584	LXCO2	1.54248	LYHC	5.172768

WT PCT ADSORBED BY NODES

LXCO2	1.7029	1.7279	1.7332	1.7220	1.6903
LYH2O	7.0497	7.0823	7.0441	6.9432	6.7569

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.60141E-04	-0.35155E-04	-0.11349E-04	0.12060E-04	0.35684E-04	0.60311E-04
H2O	-0.29603E-03	-0.17090E-03	-0.54665E-04	0.58087E-04	0.17143E-03	0.29067E-03
TOTAL	-0.35617E-03	-0.20606E-03	-0.66014E-04	0.70147E-04	0.20711E-03	0.35098E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.24866E-04	-0.23677E-04	-0.23270E-04	-0.23494E-04	-0.24528E-04
H2O	-0.12492E-03	-0.11597E-03	-0.11247E-03	-0.11308E-03	-0.11905E-03
TOTAL	-0.14981E-03	-0.13965E-03	-0.13574E-03	-0.13657E-03	-0.14357E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.16885E-02	0.30513	0.38735	0.41260	0.38973	0.30825	0.17183E-02
H2O	0.83115E-02	1.5020	1.8831	1.9875	1.8724	1.4857	0.82817E-02
TOTAL	0.10000E-01	1.8072	2.2705	2.4001	2.2621	1.7940	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	108.000	PCTL	7.96423	TCOUT	531.000			EFFH	4.25887	EFFC	3.30750
LTH2O	5.46484	LTCO2	1.47939	LYH2O	4.02119	LZH2	2.46365	LXCO2	1.34227	LYHC	5.137117

WT PCT ADSORBED BY NODES

LXCO2	1.4578	1.4950	1.5044	1.4910	1.4487
LYH2O	6.5263	6.5968	6.5733	6.4698	6.2580

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.48061E-04	-0.28066E-04	-0.90573E-05	0.96254E-05	0.28490E-04	0.48204E-04
H2O	-0.25638E-03	-0.14791E-03	-0.47302E-04	0.50269E-04	0.14839E-03	0.25179E-03
TOTAL	-0.30444E-03	-0.17597E-03	-0.56359E-04	0.59894E-04	0.17688E-03	0.29999E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.19917E-04	-0.18908E-04	-0.18575E-04	-0.18763E-04	-0.19634E-04
H2O	-0.10629E-03	-0.10037E-03	-0.97318E-04	-0.97890E-04	-0.10322E-03
TOTAL	-0.12621E-03	-0.11928E-03	-0.11589E-03	-0.11665E-03	-0.12285E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.15767E-02	0.26375	0.33473	0.35651	0.33679	0.26649	0.16067E-02
H2O	0.84213E-02	1.4070	1.7641	1.8620	1.7543	1.3921	0.83933E-02
TOTAL	0.10000E-01	1.6708	2.0988	2.2185	2.0911	1.6585	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	110.000	PCTL	7.34746	TCOUT	531.000			EFFH	3.73456	EFFC	2.8885
LTH2O	6.05830	LTCO2	1.28916	LYH2O	3.66460	LZH2	2.39371	LXCO2	1.18334	LYHC	0.109817

WT PCT ADSORBED BY NODES

LXCO2	1.2602	1.3073	1.3199	1.3046	1.2538
LYH2O	6.0708	6.1747	6.1640	6.0581	5.8239

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.39094E-04	-0.22844E-04	-0.73750E-05	0.78368E-05	0.23193E-04	0.39221E-04
H2O	-0.22393E-03	-0.12919E-03	-0.41326E-04	0.43914E-04	0.12964E-03	0.21996E-03
TOTAL	-0.26302E-03	-0.15204E-03	-0.48701E-04	0.51751E-04	0.15283E-03	0.25918E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.16188E-04	-0.15388E-04	-0.15125E-04	-0.15274E-04	-0.15964E-04
H2O	-0.94569E-04	-0.87654E-04	-0.85015E-04	-0.85514E-04	-0.90153E-04
TOTAL	-0.11076E-03	-0.10304E-03	-0.10014E-03	-0.10079E-03	-0.10612E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.14863E-02	0.23082	0.29311	0.31226	0.29495	0.23328	0.15132E-02
H2O	0.85137E-02	1.3222	1.6577	1.7499	1.6487	1.3083	0.84868E-02
TOTAL	0.10000E-01	1.5530	1.9509	2.0621	1.9437	1.5416	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	112.000	PCTL	6.61758	TCOUT	531.000			EFFH	3.30120	EFFC	2.54385
LTH2O	5.68431	LTCO2	1.13327	LYH2O	3.35836	LZH2	2.32594	LXCO2	1.04688	LYHC	0.863919E-01

WT PCT ADSORBED BY NODES

LXCO2	1.0985	1.1533	1.1685	1.1518	1.0943
LYH2O	5.6717	5.8046	5.8049	5.6969	5.4434

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.32263E-04	-0.18887E-04	-0.61033E-05	0.64839E-05	0.19179E-04	0.32381E-04
H2O	-0.19709E-03	-0.11379E-03	-0.36420E-04	0.38691E-04	0.11420E-03	0.19363E-03
TOTAL	-0.22936E-03	-0.13268E-03	-0.42523E-04	0.45175E-04	0.13338E-03	0.22601E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.13324E-04	-0.12717E-04	-0.12516E-04	-0.12628E-04	-0.13149E-04
H2O	-0.83154E-04	-0.77181E-04	-0.74907E-04	-0.75317E-04	-0.79281E-04
TOTAL	-0.96478E-04	-0.89898E-04	-0.87423E-04	-0.87944E-04	-0.92431E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.14067E-02	0.20399	0.25935	0.27643	0.26102	0.20624	0.14327E-02
H2O	0.85933E-02	1.2462	1.5626	1.6496	1.5543	1.2333	0.85673E-02
TOTAL	0.10000E-01	1.4502	1.8220	1.9260	1.8153	1.4396	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	114.000	PCTL	6.35782	TCOUT	531.000			EFFH	2.93368	EFFC	2.25680
LTH2O	5.35395	LTCO2	1.00387	LYH2O	3.09366	LZH2	2.26029	LXCO2	0.935232	LYHC	0.686399E-01

WT PCT ADSORBED BY NODES

LXCO2	0.96478	1.0253	1.0424	1.0246	0.96227
LYH2O	5.3197	5.4775	5.4672	5.3776	5.1077

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.26953E-04	-0.15821E-04	-0.51195E-05	0.54371E-05	0.16070E-04	0.27065E-04
H2O	-0.17470E-03	-0.10098E-03	-0.32345E-04	0.34352E-04	0.10135E-03	0.17165E-03
TOTAL	-0.20165E-03	-0.11681E-03	-0.37465E-04	0.39789E-04	0.11742E-03	0.19871E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.11088E-04	-0.10646E-04	-0.10497E-04	-0.10576E-04	-0.10951E-04
H2O	-0.73580E-04	-0.68467E-04	-0.66513E-04	-0.66829E-04	-0.70160E-04
TOTAL	-0.84668E-04	-0.79113E-04	-0.77010E-04	-0.77406E-04	-0.81111E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.13366E-02	0.18175	0.23145	0.24686	0.23300	0.18385	0.13620E-02
H2O	0.86634E-02	1.1781	1.4774	1.5597	1.4696	1.1660	0.86380E-02
TOTAL	0.10000E-01	1.3598	1.7088	1.8065	1.7026	1.3499	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	116.000	PCTL	5.95535	TCOUT	531.000			EFFH	2.63208	EFFC	2.01505
LTH2O	5.04018	LTCO2	0.895177	LYH2O	2.86348	LZH2	2.19669	LXCO2	0.840578	LYHC	0.545996E-01

WT PCT ADSORBED BY NODES

LXCO2	0.85296	0.91756	0.93602	0.91756	0.85178
LYH2O	5.0073	5.1863	5.2042	5.0934	4.8098

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.22755E-04	-0.13402E-04	-0.43436E-05	0.46114E-05	0.13616E-04	0.22862E-04
H2O	-0.15585E-03	-0.90232E-04	-0.28928E-04	0.30711E-04	0.90566E-04	0.15314E-03
TOTAL	-0.17860E-03	-0.10363E-03	-0.33271E-04	0.35323E-04	0.10418E-03	0.17600E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.93154E-05	-0.90110E-05	-0.89046E-05	-0.89566E-05	-0.92083E-05
H2O	-0.65492E-04	-0.61148E-04	-0.59473E-04	-0.59699E-04	-0.62452E-04
TOTAL	-0.74807E-04	-0.70159E-04	-0.68378E-04	-0.68656E-04	-0.71660E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.12741E-02	0.16304	0.20803	0.22205	0.20947	0.16501	0.12989E-02
H2O	0.87259E-02	1.1167	1.4007	1.4738	1.3934	1.1054	0.87011E-02
TOTAL	0.10000E-01	1.2797	1.6087	1.7009	1.6029	1.2704	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

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 TIME    118.000    PCTL     5.60028    TCOUT   531.000                          EFFH    2.37033    EFFC    1.83948
 LTH2O   4.79732    LTCO2  0.802968     LYH2O   2.66222    LZH2      2.13539    LXCO2  0.759475    LYHC   0.434938E-01

WT PCT ADSORBED BY NODES
 LXCO2                 0.75662      0.82593      0.84536      0.82646      0.75848
 LYH2O                  4.7284       4.9254       4.9503       4.8386       4.5439

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2            -0.19366E-04 -0.11463E-04 -0.37217E-05  0.39498E-05  0.11649E-04  0.19490E-04
 H2O            -0.13985E-03 -0.81127E-04 -0.26035E-04  0.27631E-04  0.81430E-04  0.13743E-03
 TOTAL          -0.15924E-03 -0.92590E-04 -0.29757E-04  0.31581E-04  0.93079E-04  0.15692E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                  -0.78927E-05 -0.77004E-05 -0.76283E-05 -0.76580E-05 -0.78090E-05
 H2O                  -0.58613E-04 -0.54949E-04 -0.53516E-04 -0.53658E-04 -0.55895E-04
 TOTAL                -0.66505E-04 -0.62650E-04 -0.61144E-04 -0.61316E-04 -0.63704E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2       0.12175E-02  0.14712      0.18812      0.20096      0.18948      0.14898      0.12420E-02
 H2O       0.87825E-02  1.0613       1.3315       1.4059       1.3246       1.0506       0.87580E-02
 TOTAL     0.10000E-01  1.2084       1.5196       1.6069       1.5141       1.1996       0.10000E-01

TEMPERATURES (DEG F)
 GAS                    530.00       530.00       530.00       530.00       530.00
 BED                    531.00       531.00       531.00       531.00       531.00


 TIME    120.000    PCTL     5.28484    TCOUT   531.000                          EFFH    2.14509    EFFC    1.63322
 LTH2O   4.56078    LTCO2  0.724062     LYH2O   2.48534    LZH2      2.07544    LXCO2  0.689354    LYHC   0.347377E-01

WT PCT ADSORBED BY NODES
 LXCO2                 0.67838      0.74729      0.76735      0.74823      0.67906
 LYH2O                  4.4782       4.6903       4.7211       4.6090       4.3053

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2            -0.16654E-04 -0.98879E-05 -0.32166E-05  0.34124E-05  0.10051E-04  0.16752E-04
 H2O            -0.12618E-03 -0.73355E-04 -0.23568E-04  0.25002E-04  0.73632E-04  0.12401E-03
 TOTAL          -0.14284E-03 -0.83243E-04 -0.26785E-04  0.28415E-04  0.83683E-04  0.14077E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                  -0.67364E-05 -0.66362E-05 -0.65915E-05 -0.66032E-05 -0.66732E-05
 H2O                  -0.52726E-04 -0.49658E-04 -0.48433E-04 -0.48501E-04 -0.50282E-04
 TOTAL                -0.59464E-04 -0.56294E-04 -0.55025E-04 -0.55104E-04 -0.56955E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2       0.11659E-02  0.13344      0.17102      0.18286      0.17230      0.13520      0.11900E-02
 H2O       0.88340E-02  1.0110       1.2688       1.3399       1.2623       1.0009       0.88100E-02
 TOTAL     0.10000E-01  1.1445       1.4398       1.5227       1.4346       1.1361       0.10000E-01

TEMPERATURES (DEG F)
 GAS                    530.00       530.00       530.00       530.00       530.00
 BED                    531.00       531.00       531.00       531.00       531.00
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TIME	122.000	PCTL	5.00282	TCOUT	531.000			EFFH	1.94987	EFFC	1.48796		
LTH2O	4.34661	LTCO2	0.656014	LYH2O	2.32914	LZH2	2.01767	LXCO2	0.628260	LYHC	0.277541E-01		

WT PCT ADSORBED BY NODES

LXCO2	0.60964	0.67926	0.69969	0.68052	0.61095
LYH2O	4.2525	4.4773	4.5132	4.4009	4.0901

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.14411E-04	-0.85939E-05	-0.28012E-05	0.29706E-05	0.87380E-05	0.14505E-04
H2O	-0.11443E-03	-0.66673E-04	-0.21446E-04	0.22743E-04	0.66926E-04	0.11247E-03
TOTAL	-0.12884E-03	-0.75267E-04	-0.24247E-04	0.25713E-04	0.75664E-04	0.12697E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.57928E-05	-0.57621E-05	-0.57392E-05	-0.57366E-05	-0.57422E-05
H2O	-0.47659E-04	-0.45109E-04	-0.44064E-04	-0.44066E-04	-0.45449E-04
TOTAL	-0.53452E-04	-0.50871E-04	-0.49803E-04	-0.49802E-04	-0.51192E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.11185E-02	0.12158	0.15620	0.16717	0.15742	0.12326	0.11423E-02
H2O	0.88815E-02	0.96537	1.2119	1.2799	1.2057	0.95579	0.88577E-02
TOTAL	0.10000E-01	1.0869	1.3681	1.4470	1.3631	1.0791	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	124.000	PCTL	4.74922	TCOUT	531.000			EFFH	1.77953	EFFC	1.34851
LTH2O	4.15230	LTCO2	0.596920	LYH2O	2.19057	LZH2	1.96174	LXCO2	0.574673	LYHC	0.222474E-01

WT PCT ADSORBED BY NODES

LXCO2	0.55036	0.62000	0.64058	0.62150	0.55216
LYH2O	4.0481	4.2833	4.3236	4.2114	3.8951

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.12553E-04	-0.75200E-05	-0.24561E-05	0.26038E-05	0.76482E-05	0.12642E-04
H2O	-0.10425E-03	-0.60889E-04	-0.19608E-04	0.20787E-04	0.61121E-04	0.10247E-03
TOTAL	-0.11680E-03	-0.68409E-04	-0.22064E-04	0.23391E-04	0.68769E-04	0.11511E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.50115E-05	-0.50370E-05	-0.50313E-05	-0.50174E-05	-0.49726E-05
H2O	-0.43274E-04	-0.41173E-04	-0.40281E-04	-0.40227E-04	-0.41267E-04
TOTAL	-0.48286E-04	-0.46210E-04	-0.45313E-04	-0.45244E-04	-0.46239E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.10747E-02	0.11122	0.14325	0.15346	0.14441	0.11283	0.10982E-02
H2O	0.89253E-02	0.92371	1.1600	1.2252	1.1541	0.91461	0.89018E-02
TOTAL	0.10000E-01	1.0349	1.3032	1.3786	1.2985	1.0274	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

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TIME    126.000    PCTL    4.51998    TCOUT   531.000                          EFFH    1.63306    EFFC    1.23266
LTH2O   3.97471    LTCO2   0.545276   LYH2O   2.06711     LZH2    1.90759     LXCO2   0.527393   LYHC    0.178328E-01

WT PCT ADSORBED BY NODES
 LXCO2              0.49892     0.56803     0.58660     0.56973     0.50110
 LYH2O              3.8621      4.1058      4.1498      4.0380      3.7178

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2        -0.11000E-04 -0.66205E-05 -0.21668E-05  0.22962E-05  0.67353E-05  0.11086E-04
 H2O        -0.95389E-04 -0.55851E-04 -0.18007E-04  0.19083E-04  0.56065E-04  0.93770E-04
 TOTAL      -0.1063[illegible]E-03 -0.62471E-04 -0.20174E-04  0.21380E-04  0.62800E-04  0.10486E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                -0.43610E-05 -0.44300E-05 -0.44378E-05 -0.44152E-05 -0.43313E-05
 H2O                -0.39460E-04 -0.37744E-04 -0.35986E-04 -0.36883E-04 -0.37628E-04
 TOTAL              -0.43821E-04 -0.42174E-04 -0.41423E-04 -0.41298E-04 -0.41959E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2     0.10340E-02  0.10213     0.13187     0.14140     0.13298     0.10367     0.10572E-02
 H2O     0.89660E-02  0.88561     1.1125      1.1752      1.1069      0.87693     0.89478E-02
 TOTAL   0.10000E-01  0.98774     1.2444      1.3166      1.2399      0.98059     0.10000E-01

TEMPERATURES (DEG F)
 GAS                530.00      530.00      530.00      530.00      530.00
 BED                531.00      531.00      531.00      531.00      531.00


TIME    128.000    PCTL    4.31174    TCOUT   531.000                          EFFH    1.49812    EFFC    1.13366
LTH2O   3.81186    LTCO2   0.499882   LYH2O   1.95667     LZH2    1.85519     LXCO2   0.485462   LYHC    0.144197E-01

WT PCT ADSORBED BY NODES
 LXCO2              0.45404     0.52220     0.54262     0.52404     0.45650
 LYH2O              3.6921      3.9428      3.9900      3.8787      3.5557

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2        -0.96930E-05 -0.58609E-05 -0.19221E-05  0.20363E-05  0.59642E-05  0.97741E-05
 H2O        -0.87634E-04 -0.51437E-04 -0.16603E-04  0.17590E-04  0.51634E-04  0.86152E-04
 TOTAL      -0.97327E-04 -0.57297E-04 -0.18525E-04  0.19626E-04  0.57598E-04  0.95926E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                -0.38155E-05 -0.39177E-05 -0.39359E-05 -0.39067E-05 -0.37931E-05
 H2O                -0.36125E-04 -0.34742E-04 -0.34097E-04 -0.33954E-04 -0.34446E-04
 TOTAL              -0.39941E-04 -0.38660E-04 -0.38033E-04 -0.37860E-04 -0.38240E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2     0.99592E-03  0.94086E-01 0.12180     0.13073     0.12286     0.95563E-01  0.10189E-02
 H2O     0.90041E-02  0.85066     1.0690      1.1293      1.0637      0.84235      0.89811E-02
 TOTAL   0.10000E-01  0.94474     1.1908      1.2601      1.1865      0.93792      0.10000E-01

TEMPERATURES (DEG F)
 GAS                530.00      530.00      530.00      530.00      530.00
 BED                531.00      531.00      531.00      531.00      531.00
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TIME	130.000	PCTL	4.12172	TCOUT	531.000			EFFH	1.38113	EFFC	1.04351
LTH2O	3.66196	LTCO2	0.459769	LYH2O	1.85750	LZH2	1.80446	LXCO2	0.448101	LYHC	0.115583E-01

WT PCT ADSORBED BY NODES

LXCO2	0.41468	0.48157	0.50174	0.48351	0.41735
LYH2O	3.5362	3.7925	3.8423	3.7318	3.4070

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.85844E-05	-0.52146E-05	-0.17136E-05	0.18149E-05	0.53080E-05	0.86615E-05
H2O	-0.80812E-04	-0.47548E-04	-0.15366E-04	0.16274E-04	0.47731E-04	0.79449E-04
TOTAL	-0.89396E-04	-0.52762E-04	-0.17079E-04	0.18089E-04	0.53039E-04	0.88111E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.33549E-05	-0.34822E-05	-0.35084E-05	-0.34742E-05	-0.33385E-05
H2O	-0.33197E-04	-0.32098E-04	-0.31551E-04	-0.31374E-04	-0.31652E-04
TOTAL	-0.36552E-04	-0.35581E-04	-0.35059E-04	-0.34848E-04	-0.34991E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.96026E-03	0.86943E-01	0.11284	0.12124	0.11386	0.88362E-01	0.98299E-03
H2O	0.90397E-02	0.81849	1.0289	1.0872	1.0238	0.81054	0.90170E-02
TOTAL	0.10000E-01	0.90544	1.1418	1.2084	1.1377	0.89890	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	132.000	PCTL	3.94763	TCOUT	531.000			EFFH	1.27692	EFFC	0.960312
LTH2O	3.52346	LTCO2	0.424151	LYH2O	1.76811	LZH2	1.75537	LXCO2	0.414572	LYHC	0.947395E-02

WT PCT ADSORBED BY NODES

LXCO2	0.37598	0.44537	0.46522	0.44738	0.38281
LYH2O	3.3927	3.6533	3.7054	3.5958	3.2702

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.76381E-05	-0.46609E-05	-0.15347E-05	0.16249E-05	0.47457E-05	0.77113E-05
H2O	-0.74781E-04	-0.44105E-04	-0.14269E-04	0.15107E-04	0.44275E-04	0.73524E-04
TOTAL	-0.82419E-04	-0.48766E-04	-0.15803E-04	0.16732E-04	0.49021E-04	0.81235E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.29638E-05	-0.31094E-05	-0.31416E-05	-0.31038E-05	-0.29521E-05
H2O	-0.30614E-04	-0.29758E-04	-0.29294E-04	-0.29089E-04	-0.29187E-04
TOTAL	-0.33577E-04	-0.32867E-04	-0.32436E-04	-0.32193E-04	-0.32140E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.92674E-03	0.80568E-01	0.10483	0.11274	0.10580	0.81930E-01	0.94922E-03
H2O	0.90733E-02	0.78882	0.99199	1.0483	0.98712	0.78120	0.90508E-02
TOTAL	0.10000E-01	0.86939	1.0968	1.1610	1.0929	0.86313	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

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 TIME    134.000    PCTL    3.78749    TCOUT   531.000                        EFFH    1.18366    EFFC   0.888754
 LTH2O   3.39511    LTCO2  0.392383    LYH2O   1.68725    LZH2     1.70737    LXCO2  0.384649    LYHC   0.773375E-02

WT PCT ADSORBED BY NODES
 LXCO2                  0.34926      0.41297      0.43244      0.41504      0.35220
 LYH2O                   3.2601       3.5241       3.5781       3.4695       3.1438

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2            -0.68255E-05 -0.41837E-05 -0.13803E-05  0.14610E-05  0.42609E-05  0.68948E-05
 H2O            -0.69425E-04 -0.41042E-04 -0.13292E-04  0.14069E-04  0.41200E-04  0.68261E-04
 TOTAL          -0.76250E-04 -0.45225E-04 -0.14672E-04  0.15530E-04  0.45461E-04  0.75156E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                 -0.26298E-05 -0.27882E-05 -0.28250E-05 -0.27846E-05 -0.26218E-05
 H2O                 -0.28325E-04 -0.27677E-04 -0.27235E-04 -0.27058E-04 -0.27004E-04
 TOTAL               -0.30955E-04 -0.30465E-04 -0.30110E-04 -0.29843E-04 -0.29626E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2      0.85514E-03  0.74852E-01  0.97635E-01  0.10511      0.98572E-01  0.76161E-01  0.91737E-03
 H2O      0.91049E-02  0.76137      0.95781      1.0123       0.95314      0.75435      0.90826E-02
 TOTAL    0.10000E-01  0.83623      1.0554       1.1174       1.0517       0.83021      0.10000E-01

TEMPERATURES (DEG F)
 GAS                     530.00       530.00       530.00       530.00       530.00
 BED                     531.00       531.00       531.00       531.00       531.00


 TIME    136.000    PCTL    3.63968    TCOUT   531.000                        EFFH    1.09989    EFFC   0.824649
 LTH2O   3.27575    LTCO2  0.363929    LYH2O   1.61385    LZH2     1.66190    LXCO2  0.357590    LYHC   0.633972E-02

WT PCT ADSORBED BY NODES
 LXCO2                  0.32195      0.38387      0.40291      0.38596      0.32496
 LYH2O                   3.1373       3.4037       3.4594       3.3518       3.0266

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2            -0.61237E-05 -0.37700E-05 -0.12461E-05  0.13187E-05  0.38405E-05  0.61894E-05
 H2O            -0.64647E-04 -0.38304E-04 -0.12418E-04  0.13141E-04  0.38452E-04  0.63567E-04
 TOTAL          -0.70771E-04 -0.42074E-04 -0.13664E-04  0.14460E-04  0.42293E-04  0.69757E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                 -0.23429E-05 -0.25101E-05 -0.25501E-05 -0.25080E-05 -0.23380E-05
 H2O                 -0.26290E-04 -0.25818E-04 -0.25488E-04 -0.25243E-04 -0.25062E-04
 TOTAL               -0.28633E-04 -0.28328E-04 -0.28038E-04 -0.27751E-04 -0.27400E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2      0.86528E-03  0.69707E-01  0.91148E-01  0.98223E-01  0.92049E-01  0.70966E-01  0.88726E-03
 H2O      0.91347E-02  0.73592      0.92612      0.97887      0.92163      0.72887      0.91127E-02
 TOTAL    0.10000E-01  0.80563      1.0173       1.0771       1.0137       0.79983      0.10000E-01

TEMPERATURES (DEG F)
 GAS                     530.00       530.00       530.00       530.00       530.00
 BED                     531.00       531.00       531.00       531.00       531.00
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TIME	138.000	PCTL	3.50278	TCOUT	531.000			EFFH	1.02441	EFFC	0.766362
LTH2O	3.16444	LTCO2	0.338347	LYH2O	1.54701	LZH2	1.61742	LXCO2	0.333124	LYHC	0.522362E-02

WT PCT ADSORBED BY NODES

LXCO2	0.29757	0.35761	0.37621	0.35972	0.30062
LYH2O	3.0230	3.2913	3.3443	3.2418	2.9177

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.55145E-05	-0.34093E-05	-0.11290E-05	0.11944E-05	0.34740E-05	0.55767E-05
H2O	-0.60368E-04	-0.35846E-04	-0.11633E-04	0.12307E-04	0.35985E-04	0.59363E-04
TOTAL	-0.65883E-04	-0.39256E-04	-0.12762E-04	0.13502E-04	0.39459E-04	0.64940E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.20953E-05	-0.22678E-05	-0.23101E-05	-0.22670E-05	-0.20928E-05
H2O	-0.24472E-04	-0.24150E-04	-0.23874E-04	-0.23615E-04	-0.23328E-04
TOTAL	-0.26567E-04	-0.26418E-04	-0.26184E-04	-0.25882E-04	-0.25421E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.83701E-03	0.65060E-01	0.85276E-01	0.91985E-01	0.86142E-01	0.66271E-01	0.85873E-03
H2O	0.91630E-02	0.71225	0.89665	0.94742	0.89232	0.70546	0.91413E-02
TOTAL	0.10000E-01	0.77731	0.98192	1.0398	0.97846	0.77173	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	140.000	PCTL	3.37561	TCOUT	531.000			EFFH	0.956102	EFFC	0.714836
LTH2O	3.06035	LTCO2	0.315265	LYH2O	1.46595	LZH2	1.57440	LXCO2	0.310337	LYHC	0.432777E-02

WT PCT ADSORBED BY NODES

LXCO2	0.27573	0.33386	0.35197	0.33597	0.27879
LYH2O	2.9166	3.1860	3.2441	3.1388	2.8162

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	-0.49830E-05	-0.30934E-05	-0.10262E-05	0.10855E-05	0.31529E-05	0.50420E-05
H2O	-0.56521E-04	-0.33632E-04	-0.10925E-04	0.11555E-04	0.33762E-04	0.55583E-04
TOTAL	-0.61504E-04	-0.36725E-04	-0.11951E-04	0.12641E-04	0.36915E-04	0.60625E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	-0.18607E-05	-0.20558E-05	-0.20996E-05	-0.20560E-05	-0.18801E-05
H2O	-0.22843E-04	-0.22648E-04	-0.22418E-04	-0.22148E-04	-0.21774E-04
TOTAL	-0.24724E-04	-0.24704E-04	-0.24517E-04	-0.24204E-04	-0.23654E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	0.81019E-03	0.60847E-01	0.79942E-01	0.86315E-01	0.80776E-01	0.62013E-01	0.83156E-03
H2O	0.91898E-02	0.69020	0.86917	0.91838	0.86500	0.68364	0.91683E-02
TOTAL	0.10000E-01	0.75104	0.94912	1.0052	0.94578	0.74566	0.10000E-01

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

```
 TIME    142.000    PCTL    3.25712    TCOUT   531.000                             EFFH   0.894130    EFFC   0.667639
 LTH2O   2.96276    LTCO2   0.294368   LYH2O   1.42999    LZH2    1.53277          LXCO2  0.290761    LYHC   0.360571E-02

WT PCT ADSORBED BY NODES
 LXCO2                 0.25609      0.31229      0.32992      0.31439      0.25915
 LYH2O                 2.8170       3.0871       3.1462       3.0421       2.7214

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2            -0.45173E-05 -0.28154E-05 -0.93566E-06  0.98942E-06  0.28702E-05  0.45732E-05
 H2O            -0.53050E-04 -0.31628E-04 -0.10283E-04  0.10874E-04  0.31751E-04  0.52171E-04
 TOTAL          -0.57567E-04 -0.34444E-04 -0.11219E-04  0.11864E-04  0.34622E-04  0.56744E-04

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                   -0.16936E-05 -0.18693E-05 -0.19140E-05 -0.18704E-05 -0.16947E-05
 H2O                   -0.21377E-04 -0.21290E-04 -0.21099E-04 -0.20822E-04 -0.20376E-04
 TOTAL                 -0.23071E-04 -0.23159E-04 -0.23013E-04 -0.22693E-04 -0.22071E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2        0.76471E-03  0.57016E-01  0.75082E-01  0.81143E-01  0.75885E-01  0.58139E-01  0.80591E-03
 H2O        0.92153E-02  0.66959      0.84350      0.89183      0.83948      0.66326      0.91941E-02
 TOTAL      0.10000E-01  0.72661      0.91859      0.97297      0.91536      0.72140      0.10000E-01

TEMPERATURES (DEG F)
 GAS                   530.00       530.00       530.00       530.00       530.00
 BED                   531.00       531.00       531.00       531.00       531.00


 TIME    142.008    PCTL    3.25663    TCOUT   531.000                             EFFH   0.893763    EFFC   0.667356
 LTH2O   2.96235    LTCO2   0.294282   LYH2O   1.42976    LZH2    1.53259          LXCO2  0.290679    LYHC   0.360392E-02

WT PCT ADSORBED BY NODES
 LXCO2                 0.25602      0.31217      0.32984      0.31431      0.25908
 LYH2O                 2.8167       3.0865       3.1458       3.0418       2.7210

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES
 CO2             0.67992E-03  0.68162E-03  0.68443E-03  0.68635E-03  0.68822E-03  0.68991E-03
 H2O             0.13734E-02  0.13948E-02  0.14264E-02  0.14475E-02  0.14684E-02  0.14887E-02
 TOTAL           0.20534E-02  0.20764E-02  0.21109E-02  0.21339E-02  0.21566E-02  0.21786E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES
 CO2                   -0.16931E-05 -0.28154E-05 -0.19133E-05 -0.18697E-05 -0.16940E-05
 H2O                   -0.21372E-04 -0.31628E-04 -0.21094E-04 -0.20817E-04 -0.20371E-04
 TOTAL                 -0.23065E-04 -0.34444E-04 -0.23007E-04 -0.22687E-04 -0.22065E-04

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)
 CO2        5.0000       0.57016E-01  0.75082E-01  0.81143E-01  0.75885E-01  0.58139E-01  5.0734
 H2O        10.100       0.66959      0.84350      0.89183      0.83948      0.66326      10.948
 TOTAL      15.100       0.72661      0.91859      0.97297      0.91536      0.72140      16.021

TEMPERATURES (DEG F)
 GAS                   530.00       530.00       530.00       530.00       530.00
 BED                   531.00       531.00       531.00       531.00       531.00


 TIME    144.000    PCTL    5.17910    TCOUT   531.000                             EFFH   3.89125     EFFC   [illegible]
```

LTH2O	3.84668	LTCO2	1.33253	LYH2O	2.23273	LZH2	1.61385	LXCO2	1.31533	LYHC	0.171970E-01

WT PCT ADSORBED BY NODES

LXCO2	1.6573	1.5103	1.3479	1.1724	0.97476
LYH2O	4.3400	4.1567	3.9217	3.6265	3.1880

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.61469E-03	0.54268E-03	0.46676E-03	0.39028E-03	0.31584E-03
H2O	0.13734E-02	0.10863E-02	0.86529E-03	0.69341E-03	0.55738E-03	0.44407E-03
TOTAL	0.20534E-02	0.17010E-02	0.14080E-02	0.11602E-02	0.94767E-03	0.75991E-03

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.65232E-04	0.72009E-04	0.75921E-04	0.76478E-04	0.74448E-04
H2O	0.28718E-03	0.22098E-03	0.17187E-03	0.13603E-03	0.11331E-03
TOTAL	0.35242E-03	0.29299E-03	0.24779E-03	0.21251E-03	0.18776E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.7589	4.2521	3.7065	3.1450	2.5895	2.3226
H2O	10.100	9.0427	7.1723	5.7273	4.5952	3.6788	3.2656
TOTAL	15.100	13.802	11.424	9.4337	7.7402	6.2684	5.5882

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

TIME	146.0CC	PCIL	6.52321	TCOUT	531.COC			EFFH	5.34057	EFFC	4.01804
LTH2O	4.63146	LTCO2	1.89176	LYH2O	2.92543	LZH2	1.70603	LXCO2	1.85143	LYHC	0.403343E-01

WT PCT ADSORBED BY NODES

LXCO2	2.0620	1.9969	1.9145	1.8104	1.6750
LYH2O	5.4376	5.0651	4.6735	4.2526	3.7285

FLOW RATE (LB-MOLES/MIN) BETWEEN NODES

CO2	0.67992E-03	0.66132E-03	0.63723E-C3	C.60650E-03	0.568C6E-C3	0.52074E-03
H2O	C.13734E-02	C.11681E-02	0.98533E-03	0.82467E-03	0.68422E-03	0.55869E-C3
TOTAL	0.20534E-02	0.18294E-02	0.16226E-02	C.14312E-02	0.12523E-C2	0.10794E-02

RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES

CO2	0.18606E-04	0.24092E-04	C.30727E-04	0.39434E-04	C.47321E-04
H2O	0.20537E-03	0.18275E-03	C.16C66E-03	0.14045E-03	0.12553E-03
TOTAL	0.22398E-03	0.20684E-03	0.19139E-03	0.17888E-03	0.17285E-03

PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)

CO2	5.0000	4.9313	4.7736	4.5711	4.3159	3.9995	3.8294
H2O	10.100	9.3439	7.9153	6.6518	5.5444	4.5666	4.1085
TOTAL	15.100	14.275	12.689	11.223	9.8603	8.5661	7.9379

TEMPERATURES (DEG F)

GAS	530.00	530.00	530.00	530.00	530.00
BED	531.00	531.00	531.00	531.00	531.00

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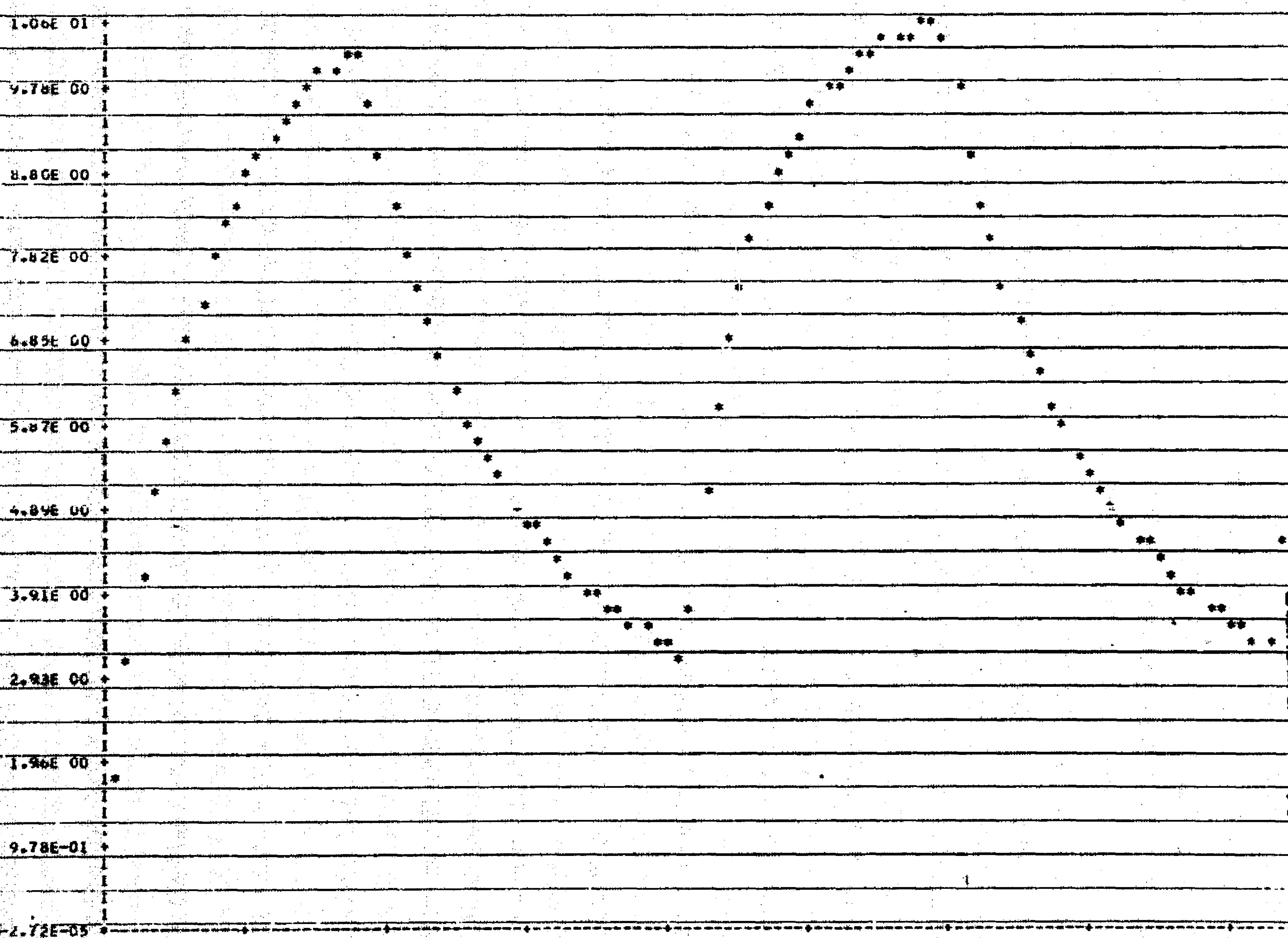
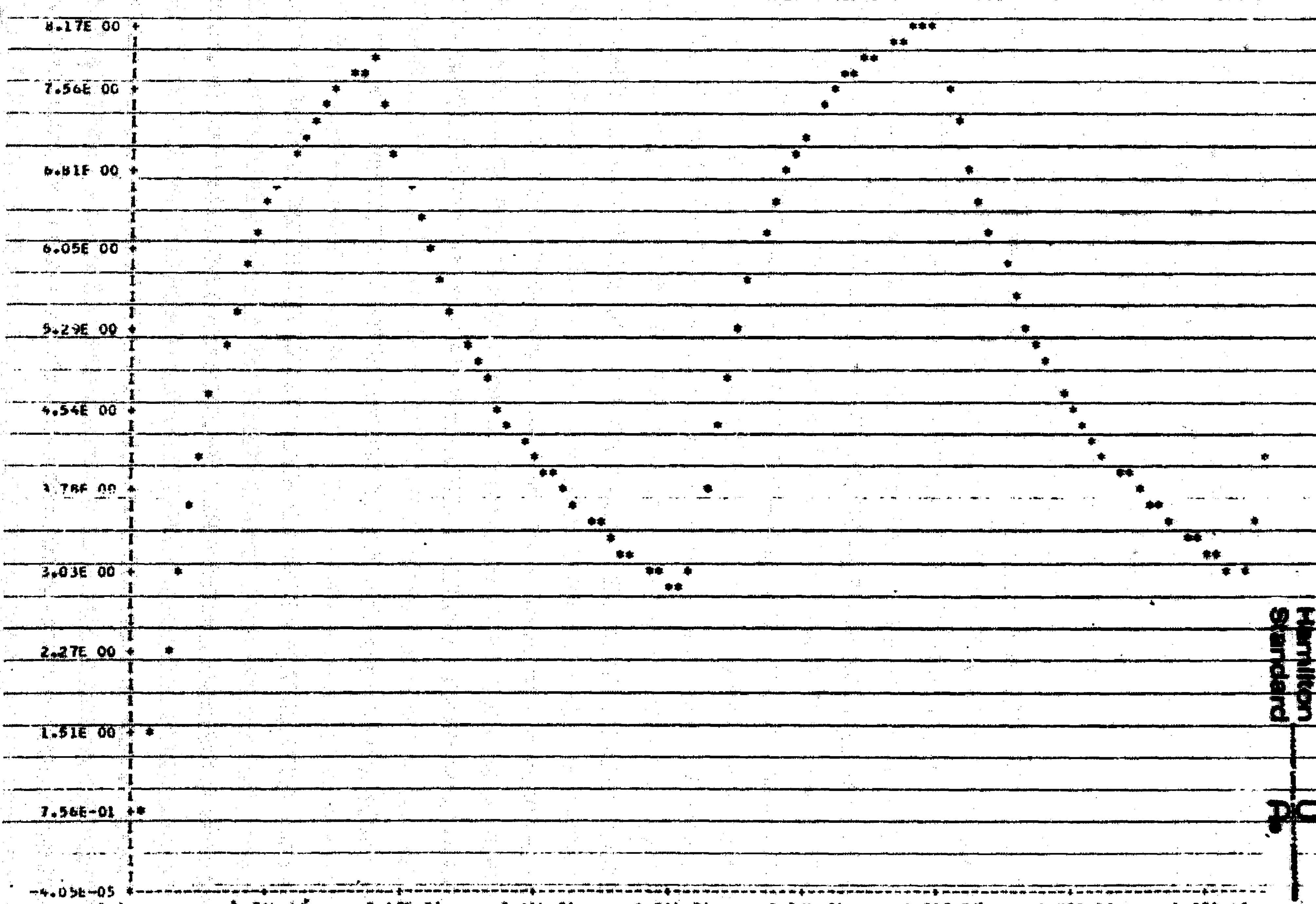
TOTAL BED LOADING

MINIMUM X= 0.0 Y= 0.0 MAXIMUM X= 1.4463281E 02 Y= 1.0561470E 01
SCALE/INCH X= 1.2257022E 01 Y= 1.1734705E 00 +OR- TOLERANCE/POINT X= 6.1285067E-01 Y= 9.7791374E-02



TOTAL H2O LOADING

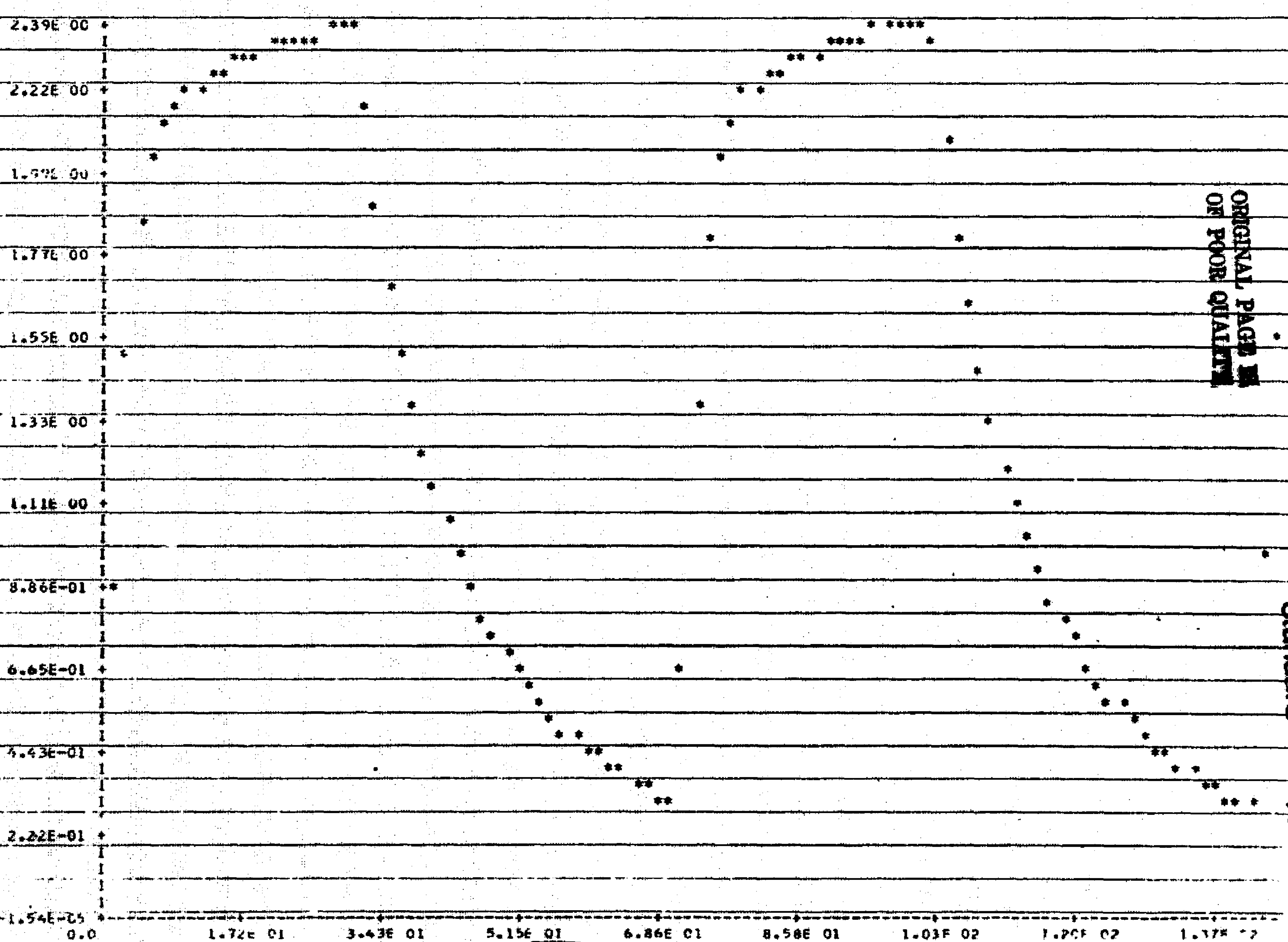
MINIMUM X= 0.0 Y= 0.0 MAXIMUM X= 1.4463281E 02 Y= 8.1620941E 00
SCALE/INCH X= 1.2257022E 01 Y= 9.0765721E-01 +OR- TOLERANCE/POINT X= 6.1285067E-01 Y= 7.5639725E-02



TOTAL CO2 LOADING

MINIMUM X= 0.0 Y= 0.0 MAXIMUM X= 1.4463281E 02 Y= 2.3923936E C[illegible]

SCALE/INCH X= 1.2257022E 01 Y= 2.6581454E-01 +OR- TOLERANCE/POINT X= 6.1285567E-01 Y= 2.2151497[illegible]



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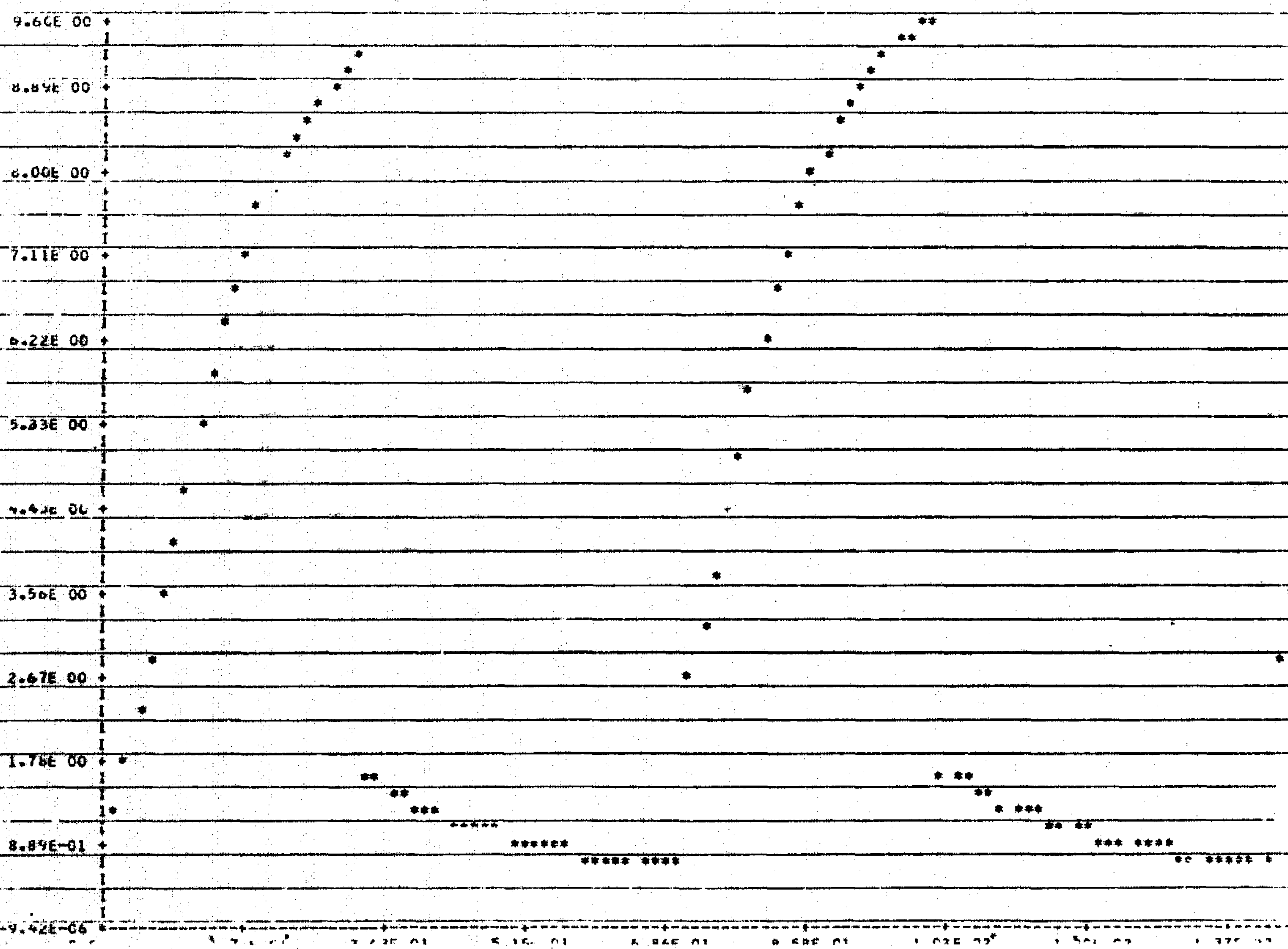
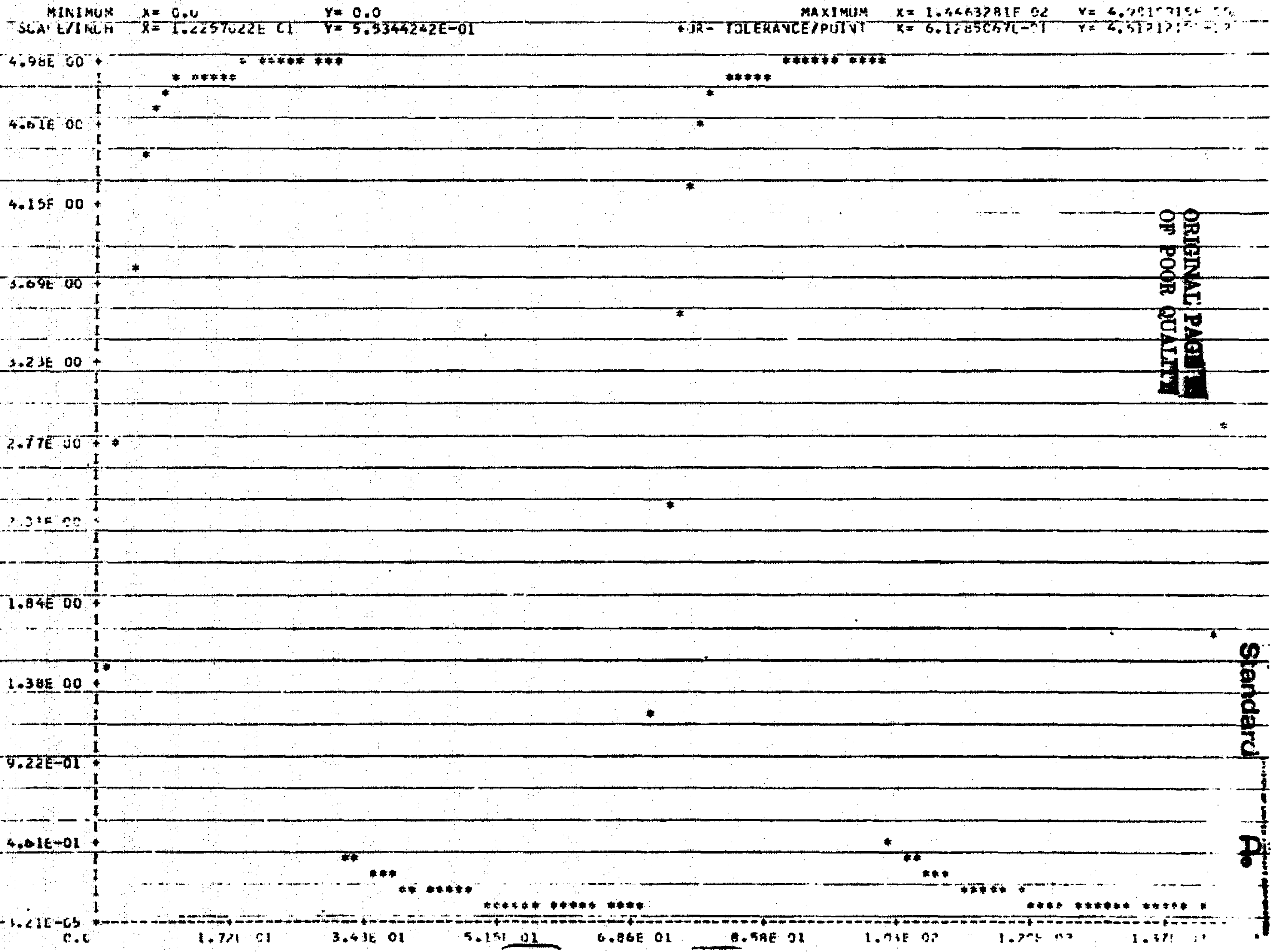
OUTLET PARTIAL PRESSURE OF H2O

MINIMUM X= 0.0 Y= 0.0 MAXIMUM X= 1.4463281E 02 Y= 9.6?26411E 00
SCALE/INCH X= 1.2257022E 01 Y= 1.0669365E 00 +OR- TOLERANCE/POINT X= 6.1285067E-01 Y= 8.8913321E-02



OUTLET PARTIAL PRESSURE OF CO2



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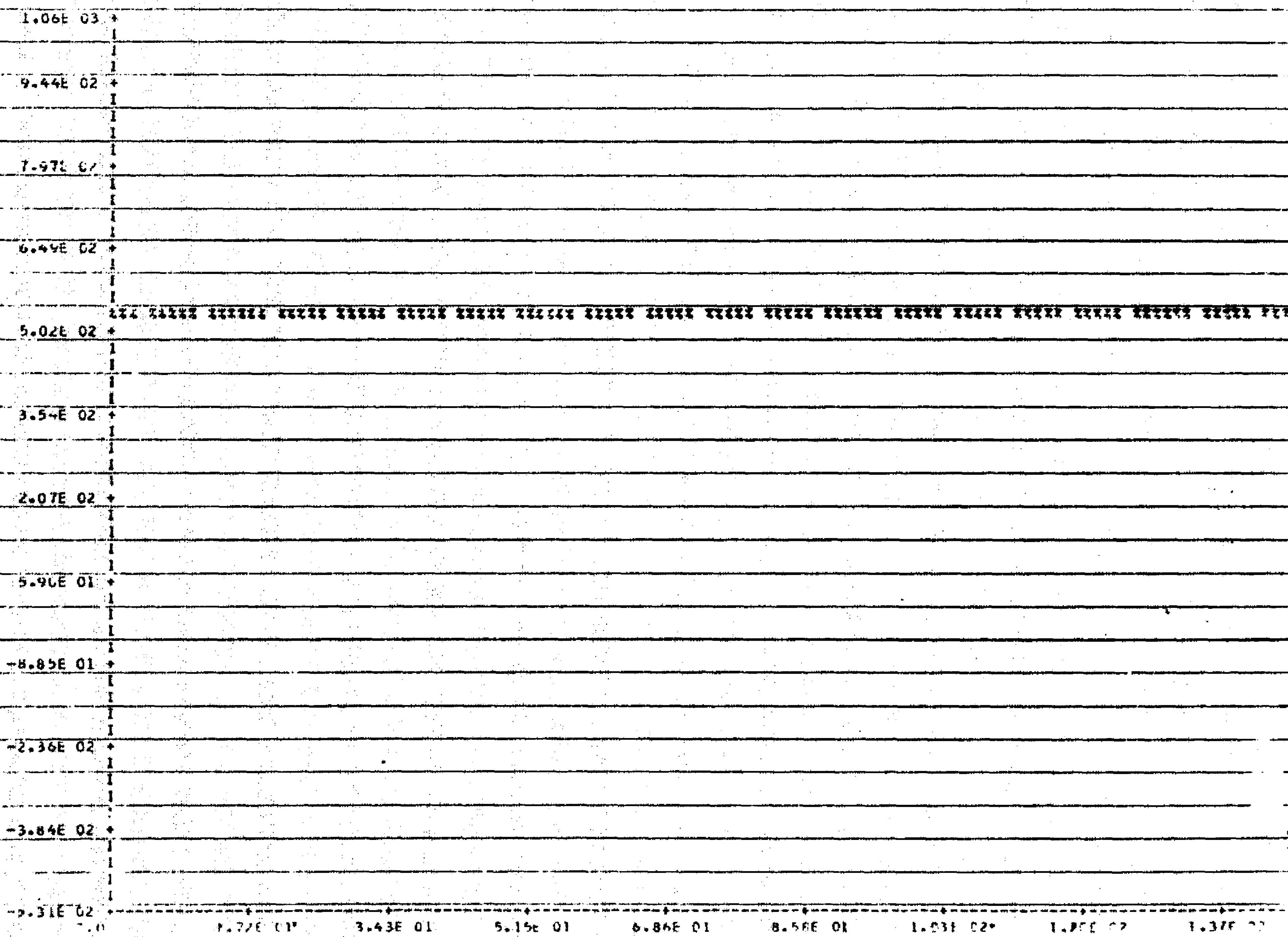
CR-115568
SVHSER-6040

OUTLET COOLANT TEMPERATURE

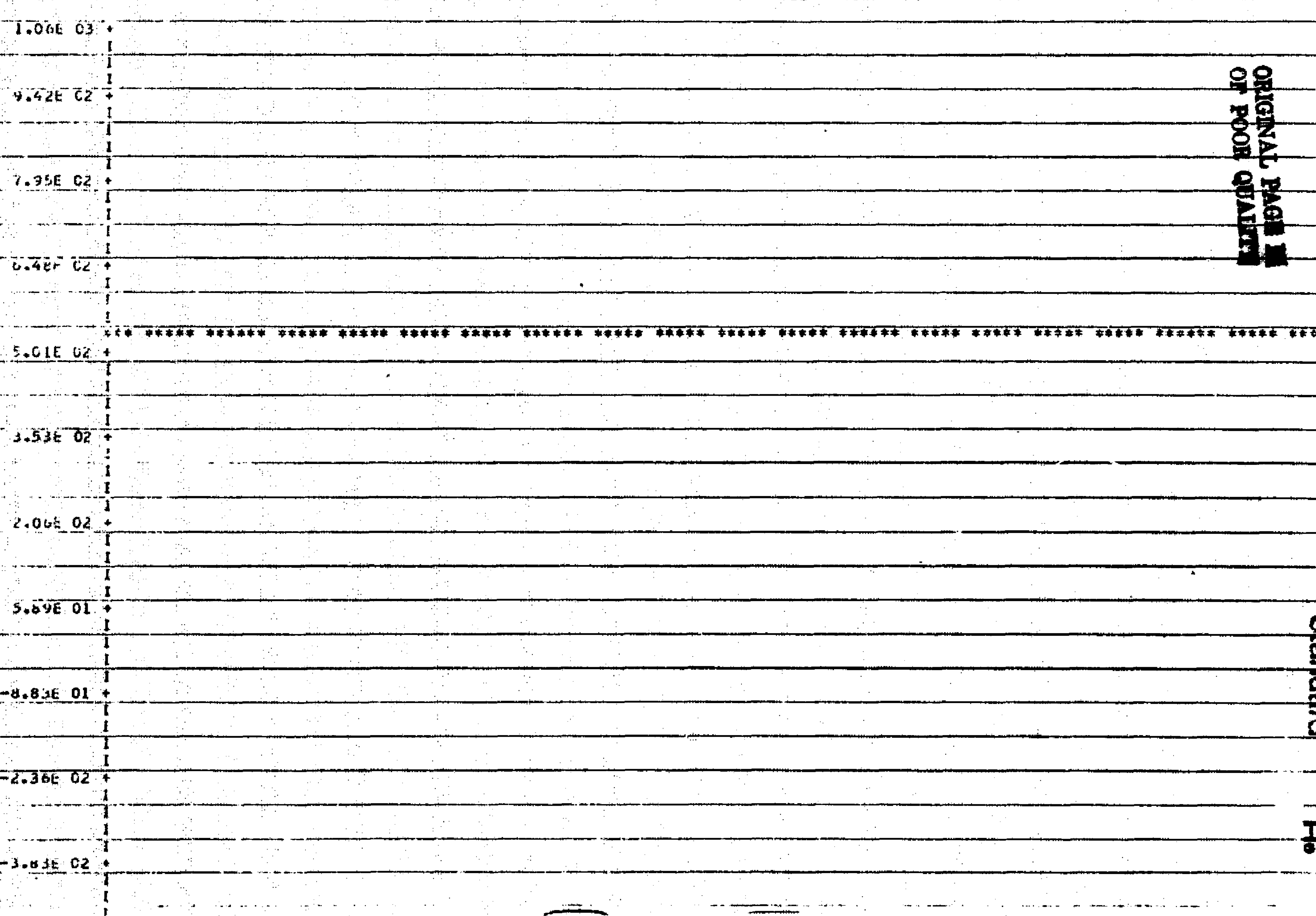
MINIMUM X= 0.0 Y=-5.3100000E 02 MAXIMUM X= 1.4463281E 02 Y= 1.[illegible]

SCALE/INCH X= 1.2257022E 01 Y= 1.7699611E 02 +OR- TOLERANCE/POINT X= 6.1285067E-01 Y= 1.475[illegible]



OUTLET PROCESS GAS TEMPERATURE

MINIMUM X= 0.0 Y=-5.3000000E 02 MAXIMUM X= 1.44632B1E 02 Y= 1.0600000E 03
SCALE/INCH X= 1.2257022E 01 Y= 1.7666278E 02 FOR- TOLERANCE/POINT X= 6.1285067E-01 Y= 1.4722221E 01



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FORTRAN IV G LEVEL  20.1              MAIN              DATE = 72160        13/18/09            PI75 0021

                C     HSC DISTRIBUTIVE MODEL  -  PHASE 3
                C     UPDATED AUGUST 1971 TO INCLUDE:
                C        1. VACUUM DESORPTION CAPABILITIES
                C        2. NONISOTHERMAL PERFORMANSE CAPABILITIES
 0001                 REAL    KX    , KXR   , KY    , KYR   , KYH   , KYHR  , KZ    ,
                     X KZR   , ICXC  , ICYH  , ICZC  , ICYHC , MZT   , MH2O  , MCO2  ,
                     X MILO2 , LXCO2 , LYH2O , LZH2  , LTH2O , LTCO2, LYHC,
                     X MZ    , MTH2O  ,ISOT ,IDES
 0002                 DIMENSION     C(200)     , HOL( 20)    , PCO2(100)  , PH2O(100)  ,
                     X DMC(100)    , DMH(100)   , XCO2(100)   ,  YH2O(100) , YHOCO(100) ,
                     X ZH2O(100)   ,
                     X XR(100)     , YR(100)    , YHCR(100)   , ZR(100)     ,
                     X      DH2O(100),PHOUT(100),
                     X DMHO(100)   , DCO2(100) , PCOUT(100) , DMCO(100)
 0003                 DIMENSION
                     X PLTIME(500), PLPCTL(500), PLPHOT(500), PLPCOT(500)
 0004                 DIMENSION PLMXC(500), PLMYC(500), PLMYH(500), PLMZH2(500)
 0005                 DIMENSION APH2O(100), APCO2(100),CON(12),C(4)
 0006                 DIMENSION WAIR(100),OR(100),TR(100),TG(100),CNI(16),
                     X  TKI(20), THB(20), TWC(20), HX(20)
                C     PROGRAM CONTROL CONSTANTS
 0007                 EQUIVALENCE      (D(1),DT      ), (D(2),TMAX    ),
                     X (D(3),PRINT   ), (D(4),PLOT    ), (D(5),EN      ),
                     X (D(6),AIND    ), (D(7),IDES    ), (D(8),ISOT    ),
                     X (D(9),XJ      )
                C     INITIAL CONDITIONS
 0008                 EQUIVALENCE      (D(11),ICXC   ), (D(12),ICYH   ),
                     X (D(13),ICZC   ), (D(14),ICYHC  ), (D(15),PIH2O  ),
                     X (D(16),PICO2  )
                C     PROGRAM CONSTANTS
 0009                 EQUIVALENCE      (D(21),XOL    ), (D(22),YOL    ),
                     X (D(23),ZOL    ), (D(24),KX     ), (D(25),KXR    ),
                     X (D(26),KY     ), (D(27),KYR    ), (D(28),KYH    ),
                     X (D(29),KYHR   ), (D(30),KZ     ), (D(31),KZR    ),
                     X (D(32),MZT    ), (D(33),PAIR   ), (D(34),Q      ),
                     X (D(35),TCIN   ), (D(36),TGI    ), (D(37),PIN    ),
                     X (D(38),POUT   ), (D(39),ADSORB ), (D(40),DESORB ),
                     X (D(41),C(1)   ), (D(45),WCTOT  ), (D(46),CNI(1) )
 0010                 EQUIVALENCE      (D(101),TKI(1)), (D(121),THB(1)),
                     X (D(141),TWC(1)), (D(161),HX(1)),( D(62), PRLAST)
                     X, (D(63),A), (D(66),EPS)
 0011                 DIMENSION  PCAVG(100), PHAVG(100)
 0012                 DIMENSION  GMO(100), DTOT(100), PI(100), IFA(100)
 0013                 COMMON/BLOK3 /PCAVG,PHAVG
 0014                 COMMON/OUTPUT/PI, FACTH, FACTC
 0015                 COMMON/BLCK1/XR,YR,YHCR,ZR
 0016                 COMMON/BLOK2/CON
                C     SET DATA ARRAY TO ZERO
 0017                 DO 1 I=1,200
 0018              1  D(I) = 0.
 0019             10  CALL BEGIN(HOL)
 0020                 WRITE(6,1020) HOL
 0021           1020  FORMAT(1H1, 20A4)
 0022                 CALL LOAD(D)
                C     SET PROGRAM CONSTANTS
 0023                 NJ = XJ
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0024          DTP = DT/NJ
0025          IND = AIND
0026          R = 555.
0027          MCO2 = 44.
0028          MH2O = 18.
0029          TIME=0.
0030          K=0
0031          NPRINT=PRINT
0032          NPLOT = (TMAX/DT +1.1)/100 + 1
0033          K=0
0034          KK = 0
0035          N=FN
0036          MZ = MZT/FN
        C     PRINT INPUT
0037          WRITE(6,1000)    DT    , TMAX  , PRINT , PLOT  , FN    , AIND  ,
             X IDES  , ISOT  , XJ    , ICXC  , ICYH  , ICZC  , ICYHC , PIH2O ,
             X PICO2 , XOL   , YOL   , ZOL   , KX    , KXR   , KY    , KYR   ,
             X KYH   , KYHR  , KZ    , KZR   , MZT   , PAIR  , Q     , TCIN
0038          WRITE(6,1016)
             X TGI   , PIN   , POUT  , ADSORB, DESORB, D(41) , D(42) , D(43) ,
             X         WCTOT , D(46) , D(47) , D(48) , D(49) , D(50) , D(51) ,
             X D(52) , D(53) , D(54) , D(55) , D(56) , D(57) , D(58) , D(59) ,
             X D(60) , D(61),D(62)
             X, A, EPS
0039     1000 FORMAT('0INPUT' /2X,
             X 8H DT     ,G12.6,8H TMAX   ,G12.6,8H PRINT  ,G12.6,
             X 8H PLOT   ,G12.6,8H FN     ,G12.6,8H IND    ,G12.6/2X,
             X 8H IDES   ,G12.6,8H ISOT   ,G12.6,8H XJ     ,G12.6,
             X 8H ICXC   ,G12.6,8H ICYH   ,G12.6,8H ICZC   ,G12.6/2X,
             X 8H ICYHC  ,G12.6,8H PIH2O  ,G12.6,8H PICO2  ,G12.6,
             X 8H XOL    ,G12.6,8H YOL    ,G12.6,8H ZOL    ,G12.6/2X,
             X 8H KX     ,G12.6,8H KXR    ,G12.6,8H KY     ,G12.6,
             X 8H KYR    ,G12.6,8H KYH    ,G12.6,8H KYHR   ,G12.6/2X,
             X 8H KZ     ,G12.6,8H KZR    ,G12.6,8H MZT    ,G12.6,
             X 8H PAIR   ,G12.6,8H Q      ,G12.6,8H TCIN   ,G12.6/)
0040     1016 FORMAT (2X,
             X 8H TGI    ,G12.6,8H PIN    ,G12.6,8H POUT   ,G12.6,
             X 8H ADSORB ,G12.6,8H DESORB ,G12.6,8H VB     ,G12.6/2X,
             X 8H XMU    ,G12.6,8H DIA    ,G12.6,8H WCTOT  ,G12.6,
             X 8H CPC    ,G12.6,8H LB     ,G12.6,8H ASHXT  ,G12.6/2X,
             X 8H AAMBI  ,G12.6,8H WHX    ,G12.6,8H WBED   ,G12.6,
             X 8H CPHX   ,G12.6,8H CPBED  ,G12.6,8H AH     ,G12.6/2X,
             X 8H AHX    ,G12.6,8H KB     ,G12.6,8H KHX    ,G12.6,
             X 8H TAMB   ,G12.6,8H HAMB   ,G12.6,8H NPT1   ,G12.6/2X,
             X 8H NPT2   ,G12.6,8H PBLAST ,G12.6,8H A      ,G12.6,8H EPS
             X,G12.6//)
        C     SET DATA ARRAY FOR AMHSC
0041          DO 12 I=1,12
0042          CON(I) = D(20+I)
0043     12   CONTINUE
        C     SET INITIAL CONDITIONS
0044          IF(IND)15,15,13
0045     13   DO 14 I=1,100
        C     INITIAL CONDITION FOR DESORPTION
0046          WAIR(I) =(PAIR*Q/(R*TGI))*28.
0047          XR(I) = 0.
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      YR(I) = 0.                                                        00001060
      YHCR(I) = 0.                                                      00001070
      ZR(I) = 0.                                                        00001080
      DMHO(I) = 0.                                                      00001090
      DCO2(I) = 0.                                                      00001100
      DMCO(I) = 0.                                                      00001110
      DH2O(I) = 0.                                                      00001120
      PCO2(I) = PICO2                                                   00001130
      PH2O(I) = PIH2O                                                   00001140
      PHOUT(I) = PIH2O                                                  00001150
      PCOUT(I) = PICO2                                                  00001160
      DMC(I) = 0.                                                       00001170
      DMH(I) = 0.                                                       00001180
      TG(I) = TGI                                                       00001190
      TB(I) = TCIN                                                      00001200
   14 CONTINUE                                                          00001210
      TCOUT = TCIN                                                      00001220
      TCOUTL = TCIN                                                     00001230
      IF(ISUI)17,17,22                                                  00001240
   22 DO 18 I=1,N                                                       00001250
   18 CALL TEMP(I,DT,TIME,N,KK,CN1,TK1,THB,TWC,HX,WCTOT,TCIN,WAIR,DMCO, 00001260
     X         DMHO,TG,TB,TCOUT)                                        00001270
      DIFF = ABS(TCOUT-TCOUTL)                                          00001280
      TCOUTL = TCOUT                                                    00001290
      IF(DIFF-1.)21,21,19                                               00001300
   19 KK = KK + 1                                                       00001310
      IF(KK .LT. 100) GO TO 22                                          00001320
      WRITE(6,1013)                                                     00001330
   21 WAIR(I) = 0.                                                      00001340
      GO TO 17                                                          00001350
   15 DO 16 I=1,100                                                     00001360
C     INITIAL CONDITION FOR ADSORPTION                                  00001370
      PCAVG(I)=0.                                                       00001371
      RHAVG(I)=0.                                                       00001372
      WAIR(I) =(PAIR*Q/(R*TGI))*28.                                     00001380
      XR(I) = 0.                                                        00001390
      YR(I) = 0.                                                        00001400
      YHCR(I) = 0.                                                      00001410
      ZR(I) = 0.                                                        00001420
      DMHO(I) = 0.                                                      00001430
      DCO2(I) = 0.                                                      00001440
      DMCO(I) = 0.                                                      00001450
      DH2O(I) = 0.                                                      00001460
      PHOUT(I) = 0.                                                     00001470
      PCOUT(I) = 0.                                                     00001480
      PCO2(I) = 0.                                                      00001490
      DMC(I) = 0.                                                       00001500
      DMH(I) = 0.                                                       00001510
      TG(I) = TGI                                                       00001520
      TB(I) = TCIN                                                      00001530
   16 PH2O(I) = 0.                                                      00001540
      PTAC=POUT*(PICO2/(PICO2+PIH2O))                                   00001541
      PTAH=POUT-PTAC                                                    00001542
      PCO2(1)=PICO2                                                     00001550
      PH2O(1)=PIH2O                                                     00001560
      DMC(1)=Q * PCO2(1) / (R     * TGI)                                00001570
```

Hamilton Standard

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FORTRAN IV G LEVEL  20.1              MAIN              DATE = 72160          13/18/09              PAGE 0006
0102                DMH(I)=Q * PH2O(I) / (R     * TG(I)                                       00001580
0103                TCOUT = TCIN                                                              00001590
0104                TCOUTL = TCIN                                                             00001600
0105                IF(ISOT)17,17,28                                                          00001610
0106          28    DO 25 I=1,N                                                               00001620
0107          25    CALL TEMP(I,DT,TIME,N,KK,CNI,TKI,THB,TWC,HX,WCTOT,TCIN,WAIR,DMCO,         00001630
                  X          DMHO,TG,TB,TCOUT)                                                00001640
0108                DIFF = ABS(TCOUT-TCOUTL)                                                  00001650
0109                TCOUTL = TCOUT                                                            00001660
0110                IF(DIFF-1.)26,26,27                                                       00001670
0111          27    KK = KK + 1                                                               00001680
0112          1013  FORMAT('0HX SUBROUTINE WILL NOT REACH SS@/)                               00001690
0113                IF(KK .LT. 100) GO TO 28                                                  00001700
0114                WRITE(6,1013)                                                             00001710
0115          26     CONTINUE                                                                 00001720
              C     INITIAL CONDITIONS SET FOR EACH CASE                                      00001730
0116          17    MTH2O = 0.                                                                00001740
0117                MTCO2 = 0.                                                                00001750
0118                DO 20 I=1,N                                                               00001760
0119                XCO2(I) = ICXC/(100.*MCO2)                                                00001770
0120                YH2O(I) = ICYH/(100.*MH2O)                                                00001780
0121                YHOCO(I)= ICYHC/(100.*MCO2)                                               00001790
0122                ZH2O(I) = ICZC/(100.*MH2O)                                                00001800
0123          20    CONTINUE                                                                  00001810
0124                WRITE (6,1005)                                                            00001820
0125          1005  FORMAT (1H1, 'OUTPUT@,/)                                                  00001830
0126                IF(TIME) 125,125,30                                                       00001840
              C     CALCULATIONS FOR N NODES EACH COMPUTING TIME INTERVAL                     00001850
0127          30    DO 122 I=1,N                                                              00001860
0128                CALL AMHSC(I,IND,JIND,IDES,DT,TG,N,PH2O,PHOUT,PCO2,PCOUT,DH2O,            00001870
                  X DCO2,DMH,DMC,XCO2,YH2O,YHOCO,ZH2O)                                        00001880
0129          122   CONTINUE                                                                  00001881
              C     IS SYSTEM ADSORBING OR DESORBING                                          00001895
0130                  IF(IND)2000,2000,2001                                                   00001900
              C     IS SYSTEM VACUUM DESORBING OR GAS PURGE DESORBING                         00001910
0131          2001    IF(IDES)2002,2002,34                                                    00001920
0132          2002  DO 35 J=1,NJ                                                              00001921
0133                DO 35 I=1,N                                                               00001922
              C     SUBROUTINE USED FOR VACUUM     DESORPTION                                 00001940
0134          35    CALL PVAC(I,DTP,N,JIND,C,DH2O,DCO2,PIN,POUT,DMHO,DMCO,PHO,PCO,            00001950
                  X TG,DMH,DMC,A,EPS)                                                         00001960
0135                PHOUT(N) = PHO                                                            00001970
0136                PCOUT(N) = PCO                                                            00001980
0137                WAIR(I) = 0.                                                              00001990
0138                GO TO 120                                                                 00002000
0139          34    PCO2(I) = 0.                                                              00002010
0140                PH2O(I) = 0.                                                              00002020
0141                DO 2003 I=1,N                                                             00002021
0142                PHOUT(I) = ABS(TG(I)*DH2O(I)*R/Q)                                         00002030
0143                PCOUT(I) = ABS(TG(I)*DCO2(I)*R/Q)                                         00002040
0144          2003  CONTINUE                                                                  00002041
0145                DMC(I) = 0.                                                               00002050
0146                DMH(I) = 0.                                                               00002060
0147          2000  DO 2004 I=1,N                                                             00002061
0148          32    CALL PCAL (I,DMC,DCO2,PCO2,PCOUT,DMCO)                                    00002070
0149                CALL PCAL (I,DMH,DH2O,PH2O,PHOUT,DMHO)                                    00002080
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Hamilton Standard

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0150          2004 CONTINUE                                                      00002081
             C     IS SYSTEM PERFORMANCE ISOTHERMAL OR NONISOTHERMAL            00002090
0151           120    IF(ISOT)2010,2010,2005                                     00002100
0152          2005 DO 2006 I=1,N                                                00002101
0153           121 CALL TEMP(I,DT,TIME,N,KK,CN1,TKI,THB,THC,HX,WCTOT,TCIN,WAIR,DMCI, 00002110
                  X         DMHO,TG,TB,TCOUT)                                    00002120
0154          2006 CONTINUE                                                      00002130
0155          2010 CONTINUE                                                      00002131
             C     CALCULATION OF OUTPUT PARAMETERS                             00002140
0156           125 CALL FOUT (TIME,DT,N,MH2O,MZT,DMH,YH2O,ZH2O,APH2O,LTH2O,LYH2O, 00002150
                  X LZH2,EFFH)                                                   00002160
0157               CALL FOUT (TIME,DT,N,MCO2,MZT,DMC,XCO2,YHOCO,APCO2,LTCO2,LXCO2, 00002170
                  X LYHC,EFFC)                                                   00002180
0158               MTH2O = 0.                                                    00002190
0159               MTCO2 = 0.                                                    00002200
0160               DO 135    I = 1,N                                             00002210
             C     CALCULATION OF H2O MASS ON BED(LBS)                          00002220
0161               MTH2O = MTH2O + APH2O(I)*MZ/100.                              00002230
             C     CALCULATION OF CO2 MASS ON BED(LBS)                          00002240
0162               MTCO2 = MTCO2 + APCO2(I)*MZ/100.                              00002250
0163           135 CONTINUE                                                      00002260
             C     CALCULATION OF TOTAL BED LOADING (H2O AND CO2)               00002270
0164               PCTL=(MTH2O + MTCO2) * 100. / MZT                             00002280
             C     SET UP PRINTER PLOT ARRAYS                                   00002290
0165               IF(PLOT .EQ. 0.) GO TO 140                                    00002300
0166                 IF(MOD(M,NPLOT) .NE. 0) GO TO 140                           00002310
0167               K=K+1                                                         00002320
0168               PLTIME(K)=TIME                                                00002330
0169               PLPCTL(K)=PCTL                                                00002340
0170               PLPHOT(K)=PHOUT(N)                                            00002350
0171               PLPCOT(K)=PCOUT(N)                                            00002360
0172               PLMXC(K) = LTH2O                                              00002370
0173               PLMYC(K) = LTCO2                                              00002380
0174               PLMTYH(K) = TCOUT                                             00002390
0175               PLMZH2(K) = TG(N)                                             00002400
0176           140   IF(MOD(M,NPRINT) .NE. 0 .AND. JIND .NE. 1) GO TO 150        00002410
             C     PRINT OUTPUT VARIABLES                                       00002420
0177                 IF(JIND .EQ. 1) WRITE(6,1033)                               00002430
0178               WRITE(6,1001) TIME, PCTL, TCOUT,                              00002431
                  X EFFH     , EFFC     , LTH2O    , LTCO2    , LYH2O    , LZH2    , 00002440
                  X LXCO2, LYHC                                                  00002450
0179          1001 FORMAT(///2X,                                                 00002451
                  X         8H TIME   G12.6,8H PCTL    G12.6,8H TCOUT   G12.6,20X, 00002470
                  X         8H EFFH   G12.6,8H EFFC     G12.6/2X,                00002471
                  X         8H LTH2O  G12.6,8H LTCO2  G12.6,8H LYH2O  G12.6,8H LZH2 00002472
                  X G12.6,8H LXCO2  G12.6,8H LYHC     G12.6)                     00002473
0180               WRITE(6,1002)                                                 00002520
0181          1002 FORMAT('0WT PCT ADSORBED BY NODES')                           00002521
0182               WRITE(6,1003) (APCO2(I),I=1,N)                                00002522
0183          1003 FORMAT('  LTCO2    ',13X,8G13.5)                              00002523
0184               WRITE(6,1004) (APH2O(I),I=1,N)                                00002524
0185          1004 FORMAT('  LTH2O    ',13X,8G13.5)                              00002525
0186               WRITE(6,1015)                                                 00002526
0187          1015 FORMAT('OFLOW RATE (LB-MOLES/MIN) BETWEEN NODES')             00002527
0188               WRITE(6,1006) (DMC(I),I=1,N), DMCO(N)                         00002528
0189          1006 FORMAT('  CO2       ', 6X,8G13.5)                             00002529
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CR-115568
SVHSER-6040

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      WRITE(6,1007) (DMH(I),I=1,N), DMHO(N)                            00002530
 1007 FORMAT('  H2O      ', 6X,8G13.5)                                 00002531
      DO 1008 I=1,N                                                    00002532
 1008 DMO(I)=DMC(I)+DMH(I)                                             00002533
      DMOL=DMCO(N)+DMHO(N)                                             00002534
      WRITE(6,1009) (DMO(I),I=1,N), DMOL                               00002535
 1009 FORMAT('  TOTAL    ', 6X,8G13.5)                                 00002536
      WRITE(6,1010)                                                    00002537
 1010 FORMAT('0RATE OF ADSORPTION (LB-MOLES/MIN) BY NODES')            00002538
      WRITE(6,1011) (DCO2(I),I=1,N)                                    00002539
 1011 FORMAT('  CO2      ',13X,8G13.5)                                 00002540
      WRITE(6,1012) (DH2O(I),I=1,N)                                    00002541
 1012 FORMAT('  H2O      ',13X,8G13.5)                                 00002542
      DO 1026 I=1,N                                                    00002543
 1026 DTOT(I)=DCO2(I) + DH2O(I)                                        00002544
      WRITE(6,1014) (DTOT(I),I=1,N)                                    00002545
 1014 FORMAT('  TOTAL    ',13X,8G13.5)                                 00002546
      WRITE(6,1018)                                                    00002547
 1018 FORMAT('0PRESSURES BY NODE, INCLUDING BOTH ENDS (MM HG)')        00002548
        IF(IND .EQ. 1) GO TO 1027                                      00002549
      WRITE(6,1017) PICO2, (PCAVG(I),I=1,N), PCOUT(N)                  00002550
      WRITE(6,1019) PIH2O, (PHAVG(I),I=1,N), PHOUT(N)                  00002551
      PTIN=PICO2 + PIH2O                                               00002552
      PTOUT=PCOUT(N) + PHOUT(N)                                        00002553
      DO 1028 I=1,N                                                    00002554
 1028 PT(I)=PCAVG(I) + PHAVG(I)                                        00002555
      WRITE(6,1022) PTIN, (PT(I),I=1,N), PTOUT                         00002556
       GO TO 1030                                                      00002557
 1027 CONTINUE                                                         00002558
      PTAH=(           POUT * (PHAVG(N)/ (PHAVG(N)+ PCAVG(N))))        00002559
      PTAC=(           POUT * (PCAVG(N)/ (PHAVG(N)+ PCAVG(N))))        00002560
      WRITE(6,1017) FACTC, (PCAVG(I),I=1,N), PTAC                      00002561
      WRITE(6,1019) FACTH, (PHAVG(I),I=1,N), PTAH                      00002562
      WRITE(6,1022) PIN, (PT(I),I=1,N), POUT                           00002563
 1017 FORMAT('  CO2      ',9G13.5)                                     00002564
 1019 FORMAT('  H2O      ',9G13.5)                                     00002565
 1022 FORMAT('  TOTAL    ',9G13.5)                                     00002566
 1030 WRITE(6,1023)                                                    00002567
 1023 FORMAT('0TEMPERATURES (DEG F)')                                  00002568
      WRITE(6,1024) (TG(I),I=1,N)                                      00002569
 1024 FORMAT('  GAS      ',13X,8G13.5)                                 00002570
      WRITE(6,1025) (TB(I),I=1,N)                                      00002571
 1025 FORMAT('  BED      ',13X,8G13.5)                                 00002572
          IF(MOD(M,2*NPRINT) .EQ. 0)  WRITE(6,1033)                    00002573
 1033 FORMAT('1')                                                      00002574
  150 CONTINUE                                                         00002830
      M=M+1                                                            00002840
C     SET UP INDICATORS FOR ADSORB AND DESORB CYCLES                   00002850
  160   IF(TIME)161,161,162                                            00002860
  161 CALL ALOGIC(TIME    ,ADSORB,DESORB,IND,JIND,TMAX,PRLAST,NPRINT)  00002861
      GO TO 163                                                        00002862
  162 CALL ALOGIC(TIME+DT,ADSORB,DESORB,IND,JIND,TMAX,PRLAST,NPRINT)   00002863
  163   CONTINUE                                                       00002864
C     RESET TIME                                                       00002870
      TIME=TIME+DT                                                     00002880
        IF(IND .NE. 0 .OR. JIND .NE. 1) GO TO 210                      00002881
```

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FORTRAN IV G LEVEL  20.1                MAIN              DATE = 72160          13/18/09                PAGE 0007

0244                DMC(1)=PICO2/(R*TGI)*Q                                                  00002882
0245                DMH(1)=PIH2O/(R*TGI)*Q                                                  00002883
0246          210   CONTINUE                                                                00002884
0247                IF(TIME-TMAX)30,30,220                                                  00002890
0248          220   CONTINUE                                                                00002900
              C     PRINTER PLOT OUTPUT                                                     00002910
0249                IF(PLOT) 10,10,230                                                      00002920
0250          230   CALL PPLOT(PLTIME,PLPCTL,K,'*',1,7,0,1,0.,'TOTAL BED LOADING            00002930
                   X                                                  ',500)                00002940
0251                CALL PPLOT(PLTIME,PLMXC ,K,'*',1,7,0,1,0.,'TOTAL H2O LOADING            00002950
                   X                                                  ',500)                00002960
0252                CALL PPLOT(PLTIME,PLMYC ,K,'*',1,7,0,1,0.,'TOTAL CO2 LOADING            00002970
                   X                                                  ',500)                00002980
0253                CALL PPLOT(PLTIME,PLPHOT,K,'*',1,7,0,1,0.,'OUTLET PARTIAL PRESSURE00002990
                   X OF H2O                                           ',500)                00003000
0254                CALL PPLOT(PLTIME,PLPCOT,K,'*',1,7,0,1,0.,'OUTLET PARTIAL PRESSURE00003010
                   X OF CO2                                           ',500)                00003020
0255                CALL PPLOT(PLTIME,PLMTVH,K,'X',1,7,0,1,0.,'OUTLET COOLANT TEMPERAT00003030
                   XURE                                               ',500)                00003040
0256                CALL PPLOT(PLTIME,PLMZH2,K,'*',1,7,0,1,0.,'OUTLET PROCESS GAS TEMP00003050
                   XERATURE                                           ',500)                00003060
0257                GO TO 10                                                                00003070
0258                END                                                                     00003080
```

COMMON BLOCK /BLOK3 / MAP SIZE 320

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
PCAVG	0	PHAVG	190						

COMMON BLOCK /OUTPUT / MAP SIZE 198

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
PT	0	FACTH	190	FACTC	194				

COMMON BLOCK /BLOK1 / MAP SIZE 640

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
XR	0	YR	190	YHCR	320	ZR	4B0		

COMMON BLOCK /BLOK2 / MAP SIZE 30

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
CON	0								

SUBPROGRAMS CALLED

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
BEGIN	248	IBCOM#	24C	LOAD	250	TEMP	254	AMHSC	258
PVAC	25C	PCAL	260	EOUT	264	ALOGIC	268	PPLOT	26C

EQUIVALENCE DATA MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
D	618	DT	618	TMAX	61C	PRINT	620	PLOT	624
EN	628	AIND	62C	IDES	630	ISOT	634	XI	638
ICXC	640	ICYH	644	ICZC	648	ICYHC	64C	PIH2O	650
PICO2	654	XOL	668	YOL	66C	ZOL	670	KX	674
KXR	678	[illegible]	67C	KYR	680	KYH	684	KYHP	688
KZ	68C	KZR	690	NZT	694	PAIR	698	Q	69C
TCIN	6A0	TGI	6A4	PIN	6A8	POUT	6AC	ADSPRB	6B0
DESORB	6B4	C	6B8	WCTOT	6C8	CNI	6CC	PILAST	70C
A	710	EPS	714	TKI	7A8	THB	7E8	TWC	848
WX	898								

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
I	938	NJ	93C	DTP	940	IND	944	R	948
MCO2	94C	MH2O	950	TIME	954	M	958	NPRINT	95C
NPLOT	960	K	964	KK	968	N	96C	MZ	970
ICOUT	974	ICOUTL	978	DIFF	97C	PIAC	980	PIAH	984
MTH2O	988	MTCO2	98C	JIND	990	J	994	PHO	998
PCO	99C	LTH2O	9A0	LYH2O	9A4	LZH2	9A8	FFFH	9AC
LTCO2	9B0	LXCO2	9B4	LYHC	9B8	FFFC	9BC	PCTI	9C0
DMOL	9C4	PTIN	9C8	PTOUT	9CC				

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
HOL	9D0	PCO2	A20	PH2O	B80	DMC	D40	DMH	F00

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Hamilton Standard

FORTRAN IV G LEVEL 20.1 MAIN DATE = 72160 13/18/09 PAGE 0009

CR-115568
SVHSER-6040

XCO2	1060	YH2O	11E0	YHCO3	1380	ZH2O	1510	DH2O	15A0
PHOUT	1830	DMHO	19C0	DCO2	1B50	PCOUT	1CE0	DMCO	1E70
PLTIME	2000	PLPCTL	2700	PLPH2T	2EA0	PLPCOT	3770	PLMXC	3E40
PLMYC	4710	PLMTYH	4EE0	PLMZH2	56B0	APH2O	5E80	APCO2	5C10
WAIR	6140	QR	6330	TB	64C0	TG	6650	DMD	57E0
DTOT	6970	TFA	6B00						

FORMAT STATEMENT MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
1020	6EC0	1000	6EC9	1016	7062	1013	71E7	1005	72DC
1001	721A	1002	7285	1003	72D2	1004	72E7	1015	72FC
1006	7327	1007	733C	1009	7351	1010	7366	1011	7395
1012	73AA	1014	73DF	1018	73D4	1017	7407	1019	741A
1022	7420	1023	7440	1024	7459	1025	746E	1033	7483

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*OPTIONS IN EFFECT*  ID,BCD,SOURCE,NOLIST,DECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =      58
*STATISTICS*    SOURCE STATEMENTS =      258,PROGRAM SIZE =     35324
*STATISTICS*  NO DIAGNOSTICS GENERATED
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Hamilton Standard U A

CR-115568
SVHSER-6040

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0001            SUBROUTINE TEMP(I,DT,TIME,N,JIND,CON,TK1,THB,TWC,HX,WCTOT,TCIN,
               X                  WAIR,DMCO,DMHO,TG,TB,TOUT)
              C     SIMULATION OF AN AIR-AIR CROSSFLOW  HEAT EXCHANGER
0002            REAL      LB     , K1     , K2     , K3     , MCB    , K4     , MCHX   ,
               X    K8,   KHX   ,K11
0003            DIMENSION      WAIR(100)  , WCO2(100)  , WH2O(100)  , TK1( 20),
               X THB( 20)    , TWC( 20)    , HX( 20)    , Q3(100)    , TB(100) ,
               X                  TBPRIM(100), THXPRM(100), TCOUT(100),
               X THX(100), CON(16), TG(100), DMCO(100), DMHO(100)
              C     SET VALUES FOR CONSTANTS DURING FIRST PASS
0004            IF(JIND)1,1,10
0005          1 IF(I-1)3,3,10
0006          3 CPC     = CON(1)
0007            LB      = CON(2)
0008            ABHXT   = CON(3)
0009            AAMBT   = CON(4)
0010            WHX     = CON(5)
0011            WBED    = CON(6)
0012            CPHX    = CON(7)
0013            CPBED   = CON(8)
0014            AB      = CON(9)
0015            AHX     = CON(10)
0016            KB      = CON(11)
0017            KHX     = CON(12)
0018            TAMB    = CON(13)
0019            HAMB    = CON(14)
0020            NPT1    = CON(15)
0021            NPT2    = CON(16)
0022            DELL=LB / N
0023            K3=KB * AB / DELL
0024            K4=KHX * AHX / DELL
0025            WC=WCTOT/ N
0026            ABHX = ABHXT/N
0027            AAMB = AAMBT/N
0028            ACHX=ABHX + AAMB
0029            MCHX = WHX*CPHX/N
0030            MCB  = WBED*CPBED/N
0031            DO 2    J = 1,N
0032            THX(J) = TG(J)
0033            TB(J) = TG(J)
0034          2 CONTINUE
              C     WRITE HEAT EXCHANGER INPUT
0035            WRITE(6,1011)
0036       1011 FORMAT('OHB#F%K1< TABLE@)
0037            WRITE(6,1012) (TK1(J),J=1,NPT1)
0038       1012 FORMAT(1X,10G12.6)
0039            WRITE(6,1012) (THB(J),J=1,NPT1)
0040            WRITE(6,1013)
0041       1013 FORMAT('OHHX#F%WC< TABLE@)
0042            WRITE(6,1012) (TWC(J),J=1,NPT2)
0043            WRITE(6,1012) (HX (J),J=1,NPT2)
0044         10 CONTINUE
              C     CALCULATE CONSTITUENT WEIGHT FLOW
0045            WCO2(I) = DMCO(I)*44.
0046            WH2O(I) = DMHO(I)*18.
              C     CALCULATE HEAT OF ABSORPTION
```

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0047           QR(I) = DMHO(I)* 1400. + DMCO(I)*1400.
0048           KI=WAIR(I) + WCO2(I) + WH2O(I)
0049           IF(KI .EQ. 0.) GO TO 11
0050           K2=(WAIR(I) * .24 + WCO2(I) * .2 + WH2O(I) * .44) / KI
0051           GO TO 12
0052      11   K2 = 0.
0053      12   KI1 = ABS(KI)
0054             IF(I .EQ. 1) TGI=TG(1)
          C    OBTAIN HEAT TRANSFER COEFFICIENT BETWEEN BED AND HEAT EXCHANGER AS
          C    A FUNCTION OF WEIGHT FLOW THROUGH BED
0055      20   CALL UNLIN(NPT1,TKI,THB,KI1,HB,IOF)
0056             IF(IOF .NE. 0) WRITE(6,1000) IOF
0057    1000   FORMAT('OKI OFF TABLE - IOF=',I1)
          C    OBTAIN HEAT TRANSFER COEFFICIENT BETWEEN HEAT EXCHANGER AND
          C    AMBIENT AS A FUNCTION OF COOLANT FLOW RATE
0058           CALL UNLIN(NPT2,TWC, HX,WC,HXX,IOF)
0059             IF(IOF .NE. 0) WRITE(6,1001) IOF
0060    1001   FORMAT ('OWC OFF TABLE - IOF=',I1)
0061           IF(KI1 .EQ. 0.) GO TO 21
0062           A = HB*ABHX/(KI1*K2)
0063           AA = EXP(-A)
0064           GO TO 22
0065      21    AA = 0.
          C    CALCULATION OF HEAT FLOW FROM PROCESS GAS TO BED
0066      22   Q1 = (TGI-TB(I))*KI*K2*(1.-AA)
0067           UBHX=HB * HXX/ (HB + HXX)
          C    CALCULATION OF HEAT FLOW FROM HEAT EXCHANGER TO BED
0068           Q2=UBHX * ABHX * (THX(I) - TB(I))
0069             IF(I-1)40,40,30
          C    CALCULATION OF NODAL CONDUCTIVE HEAT FLOW IN BED
0070      30   Q3=K3 * (TB(I-1) - TB(I))
          C    CALCULATION OF NODAL CONDUCTIVE HEAT FLOW IN HEAT EXCHANGER
0071           Q7=K4 * (THX(I-1) - THX(I))
0072            GO TO 50
0073      40   Q3=0.
0074           Q7=0.
0075      50     IF(I-N)60,70,70
          C    CALCULATION OF NODAL CONDUCTIVE HEAT FLOW IN BED
0076      60   Q4=K3 * (TB(I+1) - TB(I))
          C    CALCULATION OF NODAL CONDUCTIVE HEAT FLOW IN HEAT EXCHANGER
0077           Q8=K4 * (THX(I+1) - THX(I))
0078            GO TO 80
0079      70   Q4=0.
0080           Q8=0.
0081      80   CONTINUE
          C    CALCULATE BED TEMPERATURE AND PROCESS GAS TEMPERATURE
0082           TB(I) = TB(I) + (Q1 + Q2 + QR(I) + Q3 + Q4) * DT /MCB
0083           TG(I) = TB(I) + (TGI - TB(I))*AA
0084           TGI = TG(I)
0085           B=HXX* ACHX / (WC * CPC)
          C    CALCULATION OF HEATFLOW FROM COOLANT GAS TO HEAT EXCHANGER
0086           Q5=WC * CPC * (1. - EXP(-B)) * (TCIN - THX(I))
0087           UAMB = HXX * HAMB / (HXX + HAMB)
          C    CALCULATION OF HEAT FLOW FROM AMBIENT TO HEAT EXCHANGER
0088           Q6=UAMB * AAMB * (TAMB - THX(I))
          C    CALCULATE HEAT EXCHANGER AND COOLANT OUTLET TEMPERATURES
```

```
          THX(I) = THX(I) + (Q5 - Q2 + Q6 + Q7 + Q8)* DT / MCHX
          TCOUT(I)=THX(I) + (TCIN - THX(I)) * EXP(-B)
          IF(I-N)110,100,100
      100 TOUT1= 0.
          DO 105  I=1,N
          TOUT1= TOUT1+ TCOUT(I)
      105 CONTINUE
C     CALCULATION OF COOLANT OUTLET TEMPERATURE
          TOUT = TOUT1/N
      110 CONTINUE
          RETURN
          END
```

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SUBPROGRAMS CALLED

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
IBCOM#	134	UNLIN	138	EXP	13C				

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
JINO	180	I	184	CPC	188	L3	18C	A3HXT	190
AAMBT	194	WHX	198	WBED	19C	CPHX	1A0	CPRED	1A4
AB	1A8	AHX	1AC	KB	1B0	KHX	1B4	TAMP	1B8
HAMB	1BC	NPT1	1C0	NPT2	1C4	DELL	1C8	N	1CC
K3	1D0	K4	1D4	WC	1D8	WCTOT	1DC	A3HX	1E0
AAMB	1E4	ACHX	1E8	MCHX	1EC	MCB	1F0	J	1F4
K1	1F8	K2	1FC	K11	200	TGI	204	H3	208
IOF	20C	HXX	210	A	214	AA	218	Q1	21C
UBHX	220	Q2	224	Q3	228	Q7	22C	Q4	230
Q8	234	DT	238	B	23C	Q5	240	TCIN	244
UAMB	248	Q6	24C	TOUT1	250	TOUT	254	TIME	258

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
WAIR	25C	WCO2	260	WH2O	3F0	TKI	59[illegible]	THP	594
TWC	5B8	HX	5BC	OR	590	TB	720	TBPRIM	724
THXPRM	8B4	TCOUT	A44	THX	BD4	CON	D64	TG	D68
DMCO	D6C	DMHO	D70						

FORMAT STATEMENT MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
1011	D74	1012	D87	1013	D90	1000	DA4	1001	DBE

```
*OPTIONS IN EFFECT*  ID,BCD,SOURCE,NOLIST,DECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = TEMP     , LINECNT =        58
*STATISTICS*    SOURCE STATEMENTS =         99,PROGRAM SIZE =       5992
*STATISTICS*  NO DIAGNOSTICS GENERATED
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CR-115568
SVHSER-6040

```
0001          SUBROUTINE ANHSC(I,IND,JIND,IDES,DT,T,N,PH2O,PHOUT,PCO2,PCOUT,     00001250
             X DH2O,DCO2,DMH,DMC,XCO2,TYH2O,YHDCO,ZH2O)                          00001260
0002          REAL KX,KXR,KY,KYR,KYH,KYHR,KZ,KZR,MZ,MZT,MCO2,MH2O                00001270
0003          COMMON/BLOK1/XR,YR,YHCR,ZR                                         00001280
0004          COMMON/BLOK3/PCAVG,PHAVG                                           00001290
0005          COMMON/BLOK2/CON                                                   00001300
0006          DIMENSION PH2O(100),PHOUT(100),PCO2(100),PCOUT(100),DH2O(100),     00001310
             X        DCO2(100),DMH(100)   ,DMC(100) ,XCO2(100) ,YH2O(100),     00001320
             X      YHDCO(100) ,ZH2O(100) ,XR(100)   ,YR(100)    ,YHCR(100),    00001330
             X           ZR(100),CON(12),TYH2O(100),PHAVG(100),PCAVG(100),      00001340
             X T(100)                                                            00001350
0007          EQUIVALENCE   (CON(1),XOL  ),(CON(2),YOL  ),(CON(3),ZOL  ),       00001360
             X(CON(4),KX  ),(CON(5),KXR  ),(CON(6),KY   ),(CON(7),KYR  ),        00001370
             X(CON(8),KYH ),(CON(9),KYHR ),(CON(10),KZ  ),(CON(11),KZR ),        00001380
             X(CON(12),MZT)                                                      00001390
0008          MZ = MZT/N                                                         00001400
0009          MH2O= 18.                                                          00001410
0010          MCO2= 44.                                                          00001420
      C       CONVERT ULTIMATE CAPACITY FROM PERCENT TO LB-MOLES/LB              00001430
0011          XO = XOL/(100.*MCO2)                                               00001440
0012          YO = YOL/(100.*MH2O)                                               00001450
0013          ZO = ZOL/(100.*MH2O)                                               00001460
0014          YH2O(I) = TYH2O(I) - YHDCO(I)                                      00001470
0015          IF(JIND .EQ. -1) GO TO 3                                           00001480
0016          IF(IND-JIND)2,1,2                                                  00001490
0017        2 IF(IDES)7,7,1                                                      00001500
0018        1 PCAVG(I) = (PCO2(I) + PCOUT(I))/2.                                 00001510
      C       CALCULATE AVERAGE NODE PARTIAL PRESSURES IF NOT ON VACUUM DESORPTI00001520
0019          PHAVG(I) = (PH2O(I) + PHOUT(I))/2.                                 00001530
0020          GO TO 7                                                            00001540
0021        3 IF(I .GT. 1) GO TO 1                                               00001550
0022        4 DO 6 J=1,100                                                       00001560
0023          PCAVG(J) = (PCO2(J) + PCOUT(J))/2.                                 00001570
0024        6 PHAVG(J) = (PH2O(J) + PHOUT(J))/2.                                 00001580
      C       CALCULATE  NODAL ADSORPTION RATES FOR EACH CONSTITUENT AT EACH SIT00001590
0025        7 XR(I) = KX * PCAVG(I) *(XO - XCO2(I)) - KXR * XCO2(I)              00001600
0026          YR(I) = KY * PHAVG(I) *(YO -TYH2O(I)) - KYR * YH2O(I)              00001610
0027          YHCR(I)=YH2O(I)*KYH * PCAVG(I) - YHDCO(I) * KYHR                   00001620
0028          ZR(I) = KZ * PHAVG(I) * (ZO - ZH2O(I)) - KZR * ZH2O(I)             00001630
0029            IF(IND)5,5,53                                                    00001640
      C       LIMITING H2O ADSORPTION RATE                                       00001650
0030        5   IF(YR(I)+ZR(I) - DMH(I)/MZ)30,30,20                              00001660
0031       20 YR(I) = (YR(I) / (YR(I) + ZR(I)))* DMH(I) / MZ                     00001680
0032          ZR(I) = DMH(I) /MZ - YR(I)                                         00001690
      C       LIMITING CO2 ADSORPTION RATE                                       00001700
0033       30   IF(XR(I)+YHCR(I) - DMC(I)/MZ)60,60,50                            00001710
0034       50 XR(I) = (XR(I) / (XR(I) + YHCR(I)))*DMC(I) / MZ                    00001730
0035          YHCR(I)= DMC(I) /MZ - XR(I)                                        00001740
0036           GO TO 60                                                          00001741
0037       53 DUM=(TYH2O(I)+ ZH2O(I))/DT                                         00001742
0038            IF(DUM + YR(I) + ZR(I))54,55,55                                  00001743
0039       54 ZR(I)=ZR(I)/(YR(I)+ZR(I))*DUM                                      00001744
0040          YR(I)=DUM-ZR(I)                                                    00001745
0041       55 DUM=(XCO2(I) + YHDCO(I))/DT                                        00001746
0042            IF(DUM + XR(I) + YHCR(I))56,60,60                                00001747
0043       56 XR(I)=XR(I)/(XR(I)+YHCR(I))*DUM                                    00001748
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0044            YHCR(I)=DUM-XR(I)                                       00001740
0045      60    CONTINUE                                                00001750
          C     CALCULATION OF LB-MOLE/NODE OF ADSORBATES ON EACH SITE  00001760
0046            XCO2(I) = XCO2(I) + XR(I) * DT                          00001770
0047            TYH2O(I) = TYH2O(I) + YR(I) * DT                        00001780
0048            YHOCO(I)= YHOCO(I)+ YHCR(I)*DT                          00001790
0049            ZH2O(I) = ZH2O(I) + ZR(I) * DT                          00001800
0050            YH2O(I) = TYH2O(I)-YHOCO(I)                             00001810
0051            DH2O(I) = (YR(I) + ZR(I)) * MZ                          00001820
0052            DCO2(I) = (XR(I) +YHCR(I))* MZ                          00001830
0053            RETURN                                                  00001840
0054            END                                                     00001850
```

COMMON BLOCK /BLOK1 / MAP SIZE 640

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
XR	0	YR	190	YHCR	320	ZR	4B0		

COMMON BLOCK /BLOK3 / MAP SIZE 320

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
PCAVG	0	PHAVG	190						

COMMON BLOCK /BLOK2 / MAP SIZE 30

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
CON	0	XOL	0	YOL	4	ZOL	8	KX	C
KXR	10	KY	14	KYR	18	KYH	1C	KYHR	20
KZ	24	KZR	28	MZT	2C				

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
MZ	110	N	114	MH2O	118	MCO2	11C	XO	120
YO	124	ZO	128	I	12C	JIND	130	IND	134
IOES	138	J	13C	DUM	140	DT	144		

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
PH2O	148	PHOUT	14C	PCO2	150	PCOUT	154	DH2O	158
DCO2	15C	DMH	160	DMC	164	XCO2	168	YH2O	16C
YHOCO	2FC	ZH2O	300	TYH2O	304	T	308		

```
*OPTIONS IN EFFECT*  ID,BCD,SOURCE,NOLIST,DECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = AMHSC    , LINECNT =       58
*STATISTICS*    SOURCE STATEMENTS =        54,PROGRAM SIZE =      2580
*STATISTICS*  NO DIAGNOSTICS GENERATED
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Hamilton Standard

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      SUBROUTINE ALOGIC (TIME,ADSORB,DESORB,IND,JIND,IMAX,PRLAST,NPRINT)
      IF(TIME) 5,5,10
    5 IF(IND)6,6,7
    6 SWITCH = ADSORB
      GO TO 8
    7 SWITCH = DESORB
    8 JIND = -1
      GO TO 60
   10 IF(TIME-SWITCH)50,20,20
   20 IF(IND)30,30,40
   30 SWITCH = SWITCH + DESORB
      IND = 1
      JIND = 1
      GO TO 60
   40 SWITCH = SWITCH + ADSORB
      IND = 0
      JIND = 1
      GO TO 60
   50 JIND = 0
   60 CONTINUE
      IF (JIND)  92, 96, 94
   92 NHCY = 0
      NTHCY = 2.* IMAX /(ADSORB + DESORB)
      GO TO 96
   94 NHCY = NHCY + 1
      IF (NTHCY - NHCY -2)  96, 98, 96
   98 NPRINT = PRLAST
   96 CONTINUE
      RETURN
      END
```

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
TIME	100	IND	104	SWITCH	108	ADSORB	10C	DESPPR	110
JIND	114	NHCY	118	NTHCY	11C	TMAX	120	NPRINT	124
PRLAST	128								

```
*OPTIONS IN EFFECT*  ID,BCD,SOURCE,NOLIST,DECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = ALOGIC   , LINECNT =       58
*STATISTICS*    SOURCE STATEMENTS =      30,PROGRAM SIZE =       890
*STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  20.1            EQUT             DATE = 72160          13/18/09              PAGE 0001

0001            SUBROUTINE EQUT (TIME,DT,N,MOLWT,MZT,DMH,X1,X2,LTOT,PCTL,PCM1,
               X   PCM2,EFF)
0002            REAL  MOLWT, MZ, MZT, LTOT
0003            DIMENSION  X1(100), X2(100), LTOT(1),DMH(100)
0004            DIMENSION AX1(100), AX2(100)
0005            IF(TIME) 10,10,20
0006       10   H2OTOT = 0.
0007            HCOTOT = 0.
0008            EFF = 100.
0009            MZ = MZT/N
0010            AMTOT1 = 0.
0011            AMTOT2 = 0.
0012       20   DO 40 I=1,N
          C     CALCULATE WEIGHT(LBS) OF CONSTITJENT ON EACH SITE/NODE
0013            AX1(I) =   X1(I)*MZ*MOLWT
0014            AX2(I) =   X2(I)*MZ*MOLWT
          C     CALCULATE PERCENT LOADING OF CONSTITUENT PER NODE
0015            LTOT(I)=   (AX1(I) + AX2(I))*100./MZ
0016       40   CONTINUE
          C     CALCULATE AMOUNT OF CONSTITUENT THRU BED EACH TIME INTERVAL  (LBS.)
0017            AMX1 = 0.
0018            AMX2 = 0.
0019            DO 50 I=1,N
          C     CALCULATE WEIGHT(LBS) OF CONSTITUENT ON EACH SITE
0020            AMX1 = AMX1 + AX1(I)
0021            AMX2 = AMX2 + AX2(I)
0022       50   CONTINUE
          C     CALCULATE TOTAL WEIGHT(LBS) OF CONSTITUENT ON BED
0023            AMTOT = AMX1 + AMX2
          C     CALCULATE TOTAL LOADING OF CONSTITUENT ON BED
0024            PCTL   = AMTOT*100./MZT
          C     CALCULATE TOTAL LOADING OF CONSTITUENT ON EACH SITE
0025            PCM1   = AMX1 *100./MZT
0026            PCM2   = AMX2 *100./MZT
0027            FCT2 = DT * DMH(1) * MOLWT
0028            IF(TIME) 70,70,60
0029       60   IF(MOLWT-18.)61,61,62
0030       61   H2OTOT = H2OTOT + FCT2
0031            IF(DMH(1) .EQ. 0.) GO TO 65
          C     CALCULATE REMOVAL EFFICIENCY
0032            AMT1D = AMTOT-AMTOT1
0033            EFF = AMT2D*100./H2OTOT
0034            GO TO 70
0035       62   HCOTOT = HCOTOT + FCT2
0036            IF(DMH(1) .EQ. 0.) GO TO 66
0037            AMT2D = AMTOT-AMTOT2
0038            EFF = AMT2D*100./HCOTOT
0039            GO TO 70
0040       65   AMTOT1 = AMTOT
0041            H2OTOT = 0.
0042            GO TO 70
0043       66   AMTOT2 = AMTOT
0044            H2OTOT = 0.
0045       70   CONTINUE
0046            RETURN
0047            END
```

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CR-115568
SVHSER-6040

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
TIME	E0	H2OTOT	E4	HCOTOT	E8	EFF	EC	M7	F0
MZI	F4	N	F8	AXTOT1	FC	AXTOT2	100	I	104
MOLWT	108	AMX1	10C	AMX2	110	AMTOT	114	PCT1	118
PCM1	11C	PCM2	120	PCT2	124	DT	128	AMI10	12C
AMI20	130								

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
X1	134	X2	138	LTOT	13C	DMM	140	AX1	144
AX2	2D4								

```
*OPTIONS IN EFFECT*  ID,BCD,SOURCE,NOLIST,DECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = FOUT    , LINECNT =       58
*STATISTICS*    SOURCE STATEMENTS =        47,PROGRAM SIZE =      2044
*STATISTICS*  NO DIAGNOSTICS GENERATED
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FORTRAN IV G LEVEL  20.1                PVAC              DATE = 72160          13/18/09                 P175 0001

0001              SUBROUTINE PVAC(I,DT,N,JIND,C,DH2O,DCO2,PIN,POUT,DMHO,DMCO,          00002720
                 X PHOUT,PCOUT,TG,DMH,DMC,A,EPS)                                       00002730
0002              COMMON/OUTPUT/PT, FACTH, FACTC                                       00002731
0003              COMMON/BLOK3/PCO2,PH2O                                               00002740
0004              DIMENSION           DMO(100),DMH(100),DMC(100),DMHO(100),            00002750
                 X          DMCO(100),PH2O(100),PCO2(100),PT(100), C(4)                00002760
                 X, DH2O(100), DCO2(100),TG(100)                                       00002770
0005              REAL  L                                                              00002780
            C     SET VALUES FOR CONSTANTS DURING FIRST PASS                           00002790
0006              IF(JIND)1,5,1                                                        00002800
0007          1   VB = C(1)                                                            00002810
0008              XMU= C(2)                                                            00002820
0009              DIA = C(3)                                                           00002830
0010              XLEN= C(4) *12.                                                      00002840
0011              R= 555.                                                              00002850
0012              L = XLEN/N                                                           00002860
0013              PI =3.1415927                                                        00002870
0014              Q= A * DIA**2 * EPS**3 /(XMU*L * (1.-EPS)**2)                        00002880
                 X * 60.  /(200.*555.*.359*144.*1728.)                                 00002881
0015              VNODE = VB/N                                                         00002890
0016              K = I + 1                                                            00002900
0017              DO 2 J=I,K                                                           00002910
            C     CALCULATE TOTAL PRESSURE                                             00002920
0018              PT(J) = PH2O(J) + PCO2(J)                                            00002930
0019          2    CONTINUE                                                            00002950
0020          5   IF(I .GT. 1) GO TO 10                                                00002960
0021              DELW=Q/TG(I)                                                         00002970
0022              FACTH=PIN * (PH2O(1) / (PH2O(1) + PCO2(1)))                          00002971
0023              FACTC=PIN * (PCO2(1) / (PH2O(1) + PCO2(1)))                          00002972
            C     CALCULATE AVERAGE TOTAL PRESSURE                                     00002980
0024              PTA = (PIN + PT(1))/2.                                               00002990
0025              DMI = DELW*PTA*(PIN-PT(1))                                           00003000
0026              IF (PT(1)) 6,6,7                                                     00003010
0027            6 DMH (1) = 0.                                                         00003020
0028              GO TO  8                                                             00003030
0029            7 DMH(1) = PH2O(1)/PT(1)*DMI                                           00003040
0030            8 DM(1) = DMI-DMH(1)                                                   00003050
0031              PTA = (PT(1) + PT(2))/2.                                             00003060
            C     CALCULATE OUTLET FLOW THROUGH FIRST NODE                             00003070
0032              DMO(1) = DELW*PTA  *(PT(1)-PT(2))                                    00003080
0033              IF(N .EQ. 1) GO TO 25                                                00003090
0034              GO TO 20                                                             00003100
0035         10   IF(I .EQ. N) GO TO  25                                               00003110
0036              DELW=Q/TG(I)                                                         00003120
            C     CALCULATE AVERAGE TOTAL PRESSURE AND OUTLET FLOW FOR NODES 2 THRU    00003130
0037              PTA = (PT(I) + PT(I+1))/2.                                           00003140
0038              DMO(I) = DELW*PTA  *(PT(I)-PT(I+1))                                  00003150
0039         15   DMH(I) = DMHO(I-1)                                                   00003160
0040              DMC(I) = DMCO(I-1)                                                   00003170
            C     CALCULATE H2O AND CO2 OUTLET FLOW RATES  - LB-MOLE/MIN/NODE          00003180
0041         20   K=I                                                                  00003190
0042                IF(DMO(I) .LT. 0.) K=K+1                                           00003191
0043              DMHO(I)=PH2O(K)/PT(K)*DMO(I)                                         00003192
0044              DMCO(I)= DMO(I) - DMHO(I)                                            00003200
            C     CALCULATE PARTIAL PRESSURES OF CO2 AND H2O AND TOTAL PRESSURE        00003210
0045              DELPC=((DMC(I)-DCO2(I)-DMCO(I))*R*TG(I)/VNODE)*DT                    00003220
```

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FORTRAN IV G LEVEL  20.1              RVAC              DATE = 72160          13/18/09              PAGE 0002

0046              DELPH=((DMH(I)-DH2O(I)-DWHO(I))*2*TG(I)/VNODE)*DT                            00003221
0047                IF(ABS(DELPC).GT. .1 * PCO2(I)) DELPC=.1 * PCO2(I)*DELPC/ABS(DEL00003222
                 XPC)                                                                           00003223
0048                IF(ABS(DELPH).GT. .1 * PH2O(I)) DELPH=.1 * PH2O(I)*DELPH/ABS(DEL00003224
                 XPH)                                                                           00003225
0049              PCO2(I)=PCO2(I) + DELPC                                                       00003226
0050              PH2O(I)=PH2O(I) + DELPH                                                       00003227
0051              IF (PCO2(I)) 16, 17, 17                                                       00003240
0052         16   PCO2(I)=FACTC                                                                 00003250
0053         17 IF ( PH2O(I)) 18,19,19                                                          00003260
0054         18   PH2O(I)=FACTH                                                                 00003270
0055         19 PT(I)    = PH2O(I) + PCO2(I)                                                    00003280
0056              PHOUT = PH2O(N)                                                               00003290
0057              PCOUT = PCO2(N)                                                               00003300
0058              IF(I .EQ. N) GO TO 23                                                         00003310
0059              GO TO 30                                                                      00003320
             C    CALCULATE AVERAGE TOTAL PRESSURE FOR  LAST NODE                               00003330
0060         25   PTA = (PT(N) + POUT)/2.                                                       00003340
0061              DELW=Q/TG(I)                                                                  00003350
             C    CALCULATE OUTLET FLOW OF LAST NODE                                            00003360
0062              DML(N) = DELW*PTA*(PT(N) - POUT)                                              00003370
0063              IF(N .EQ. 1) GO TO 20                                                         00003380
0064              GO TO 15                                                                      00003390
0065         23   PHOUT = PH2O(N)                                                               00003400
0066              PCOUT = PCO2(N)                                                               00003410
0067         30   CONTINUE                                                                      00003420
0068              RETURN                                                                        00003430
0069              END                                                                           00003440
```

Hamilton Standard

```
FORTRAN IV G LEVEL  20.1                PVAC                DATE = 72160         13/18/09            PAGE 0002
```

COMMON BLOCK /OUTPUT / MAP SIZE 198

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
PT	0	FACTH	190	FACTC	194				

COMMON BLOCK /BLOK3 / MAP SIZE 320

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
PCO2	0	PH2O	190						

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
JIND	144	VB	148	XMU	14C	DIA	150	XLEN	154
R	158	L	15C	N	160	PI	164	Q	168
A	16C	EPS	170	VNODE	174	K	178	T	17C
J	180	DELW	184	PIN	188	PIA	18C	DMI	190
DELPC	194	DT	198	DELPH	19C	PHOUT	1A0	PCOUT	1A4
POUT	1A8								

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
DMO	1AC	DMH	33C	DMC	340	DMHD	344	DMCC	348
C	34C	DH2O	350	DCO2	354	TG	358		

```
*OPTIONS IN EFFECT*  ID,BCD,SOURCE,NOLIST,DECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = PVAC     , LINECNT =       58
*STATISTICS*    SOURCE STATEMENTS =        69,PROGRAM SIZE =      2760
*STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  20.1            PCAL               DATE = 72160        13/18/09            PAGE 0001

0001             SUBROUTINE PCAL (I,DMI,DAD,PIN,POUT,DMO)                           00003450
0002             DIMENSION  DMI(1),DAD(1),PIN(1),POUT(1),DMO(1)                     00003460
0003             IF(DMI(I))5,10,5                                                   00003470
           C     CALCULATE NODAL OUTLET PARTIAL PRESSURE                            00003480
0004         5   IF(DAD(I)-DMI(I))6,7,7                                             00003490
0005         6   POUT(I) =(DMI(I)-DAD(I))* PIN(I)/DMI(I)                            00003500
           C     CALCULATE NODAL OUTLET FLOW RATE OF CONSTITUENT IN LB-MOLES/MIN    00003510
0006             IF(POUT(I))8,8,10                                                  00003520
0007         8   POUT(I) = 0.                                                       00003530
0008        10   DMO(I) =  DMI(I)-DAD(I)                                            00003540
0009             GO TO 12                                                           00003550
0010         7   DMO(I) = 0.                                                        00003560
0011             POUT(I) = 0.                                                       00003570
           C     CALCULATE NODAL INLET FLOW RATE AND PARTIAL PRESSURE               00003580
0012        12   DMI(I+1)= DMO(I)                                                   00003590
0013             PIN(I+1)=POUT(I)                                                   00003600
0014             RETURN                                                             00003610
0015             END                                                                00003620
```

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
I	C0								

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
DM1	C4	DAD	C8	PIN	CC	POUT	D0	DMO	D4

```
*OPTIONS IN EFFECT*  ID,BCD,SOURCE,NOLIST,DECK,LOAD,MAP
*OPTIONS IN EFFECT*  NAME = PCAL    , LINECNT =       58
*STATISTICS*    SOURCE STATEMENTS =        15,PROGRAM SIZE =        710
*STATISTICS*  NO DIAGNOSTICS GENERATED

*STATISTICS*  NO DIAGNOSTICS THIS STEP A
```

F88-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED MAP,LIST
DEFAULT OPTION(S) USED - SIZE=(102400,16384)

CR-115568
SVHSER-604

MODULE MAP

CONTROL SECTION			ENTRY							
NAME	ORIGIN	LENGTH	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION
MAIN	00	89FC								
TEMP	8A00	1768								
AMHSC	A168	A14								
ALOGIC	AB80	37A								
FCUT	AF00	7FC								
PVAC	B700	AC8								
PCAL	C1C8	2C6								
BEGIN *	C49C	36E								
IHCSEXP *	C800	192								
			EXP	C800						
IHCECOMH*	C998	F41								
			IHCOM#	C998	FDIOCS#	CA56	INTSWICH	D98E		
IHCCOMH2*	D8E0	65D								
			SEQDASD	DC58						
LOAD *	DF40	27C								
PPLOT *	E1C0	2274								
UNLIN *	10438	28E								
IHCFCVTH*	106F8	1190								
			ADCON#	106F8	FCVAOUTP	107A2	FCVLOUTP	10932	FCVZOUTP	10982
			FCVIOUTP	10D30	FCVEOUTP	11232	FCVCOUTP	1146C	INT6SWCH	11733
IHCEFNTH*	11898	512								
			ARITH#	11898	ADJSWTCH	11C04				
IHCFUVCH*	11DB0	44								
			OVCHK	11DB0						
IHCFEXIT*	11DF8	1C								
			EXIT	11DF8						
IHCEFIOS*	11E18	1378								
			FIOCS#	11E18	FIOCSBEP	11E1C				
IHCERRM *	13190	5BC								
			ERRMON	13190	IHCERRE	131A8				
IHCUOPT *	13750	300								
IHCFOVER*	13A50	50								
			OVERFL	13A50						
IHCSLOG *	13AA0	186								
			ALOG10	13AA0	ALOG	13AB8				
IHCFMAXR*	13C58	C9								
			MAX1	13C58	MIN1	13C6E	AMAX1	13C84	AMIN1	13C9A
IHCFRXPR*	13D28	183								
			FRXPR#	13D28						
IHCFTRCH*	13E80	28E								
			IHCTRCH	13E80	ERRTRA	13E88				
IHCUATBL*	14140	208								
PACK *	14348	182								
BLOK3	14400	320								

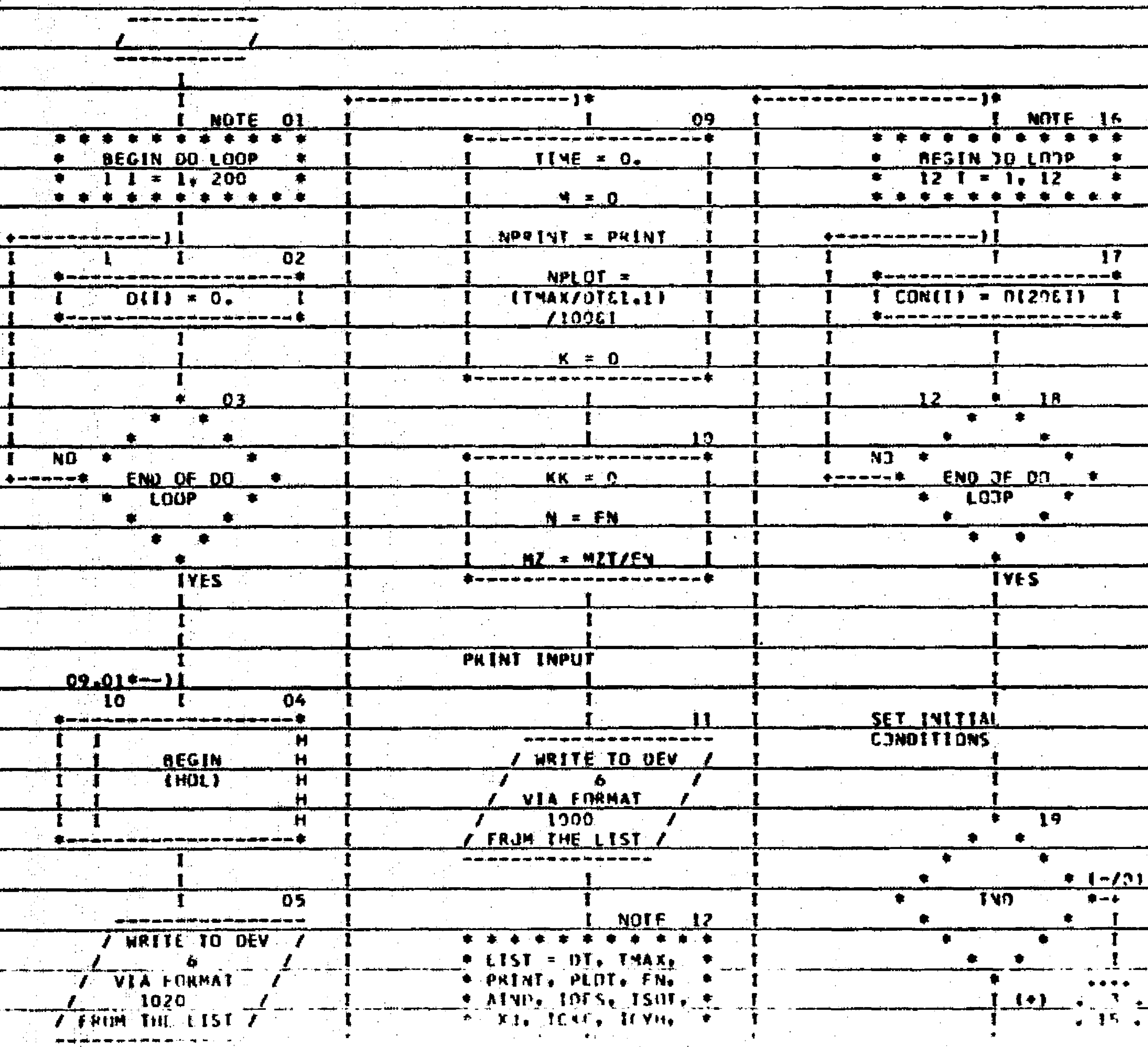
Hamilton Standard

NAME	ORIGIN	LENGTH	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION
OUTPUT	147E0	198								
BLOK1	14986	640								
BLOK2	14FC8	30								

```
ENTRY ADDRESS       00
TOTAL LENGTH     14FE8

****MAIN      DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET
```

CHART TITLE - PROCEDURES



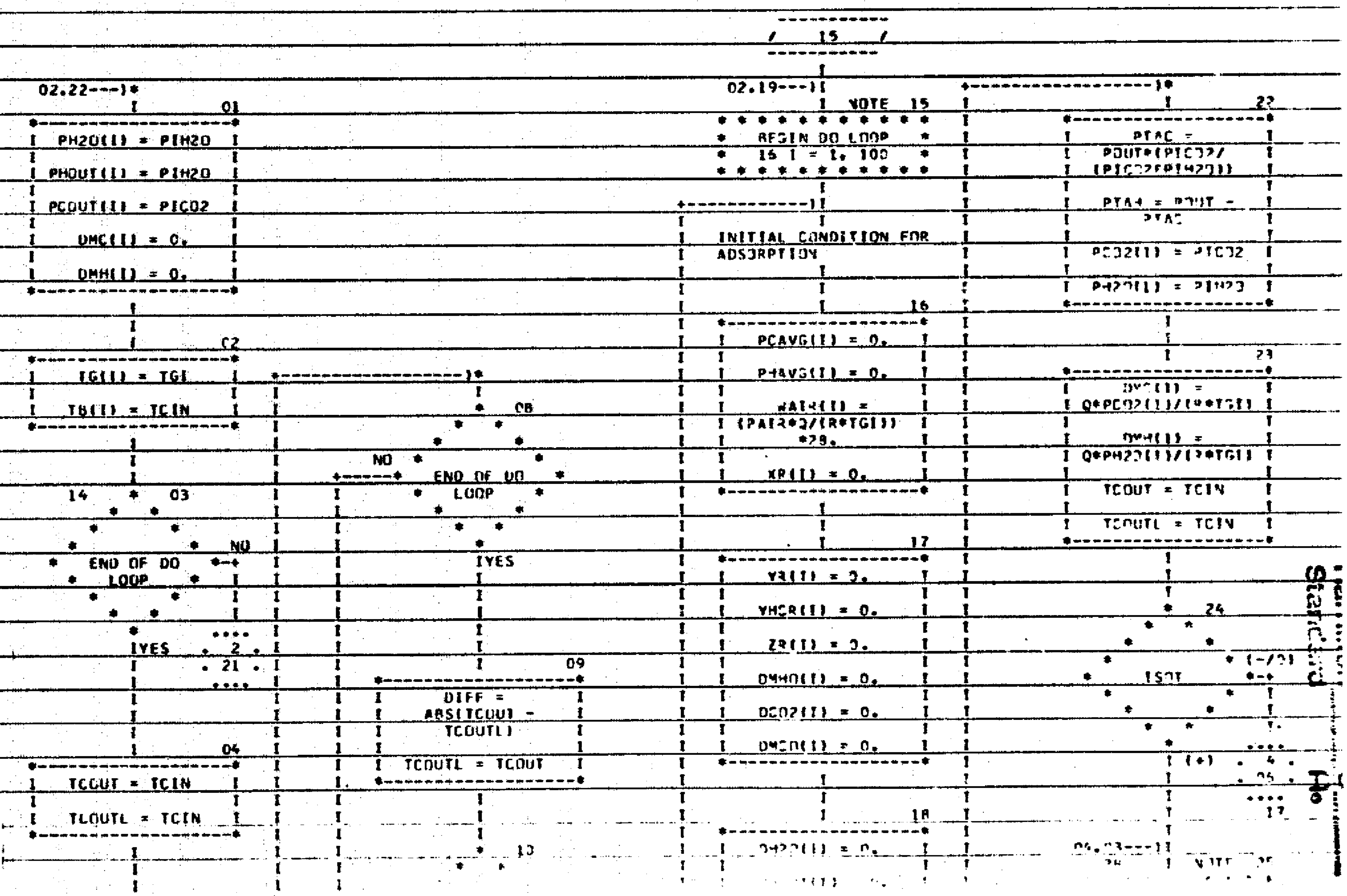
```
            I NOTE 06
* * * * * * * * * * * *
*   LIST = HOL        *
* * * * * * * * * * * *
            I
            I 07
*--------------------*
I I     LOAD         H
I I     (D)          H
I I                  H
I I                  H
*--------------------*
            I
SET PROGRAM CONSTANTS
            I 08
*--------------------*
I     NJ = XJ        I
I    DTP = DT/NJ     I
I    IND = AIND      I
I      R = 555.      I
I   MCO2 = 44.       I
I   MH2O = 18.       I
*--------------------*
            I
            +---------------+
```

```
*   PIH2O, PICO2,      *
*   XOL, YOL, ZOL,     *
*   KX, KXR, KY, KYR,  *
*   KYH, KYHR, KZ,     *
*   KZR, MZT, PAIR,    *
*      Q, TCIN         *
* * * * * * * * * * * *
          I
          I         13
  ----------------
 / WRITE TO DEV  /
/      6        /
/ VIA FORMAT   /
/    1016     /
/ FROM THE LIST /
  ----------------
          I
          I NOTE 14
* * * * * * * * * * * *
* LIST = TGI, PIN,     *
*   POUT, ADSORB,      *
*   DESORB, D(41),     *
*   D(42), D(43),      *
*   WCTOT, D(46),      *
*   D(47), D(48),      *
*   D(49), D(50),      *
*   D(51), D(52),      *
*   D(53), D(54),      *
*   D(55), D(56),      *
*   D(57), D(58),      *
*   D(59), D(60),      *
* D(61), D(62), A,     *
*        EPS           *
* * * * * * * * * * * *
          I
SET DATA ARRAY FOR
AMHSC
          I
          +---------------+
```

```
             I          15
             I
   13        I NOTE 20
* * * * * * * * * * * *
*  BEGIN DO LOOP      *
*  14 I = 1, 100      *
* * * * * * * * * * * *
             I
 03.03---->I
             I
INITIAL CONDITION FOR
DESORPTION
             I
             I          21
*--------------------*
I    WAIR(I) =       I
I (PAIR*Q/(R*TGI))   I
I     *29.           I
I                    I
I    XR(I) = 0.      I
I    YR(I) = 0.      I
I   YHCR(I) = 0.     I
I    ZR(I) = 0.      I
*--------------------*
             I
             I          22
*--------------------*
I   DNH3(I) = 0.     I
I   DCO2(I) = 0.     I
I   DHCO(I) = 0.     I
I   DH2O(I) = 0.     I
I  PCO2(I) = PICO2   I
*--------------------*
             I
             I
           -----
          / 3.01
```

Hamilton Standard

CHART TITLE - PROCEDURES



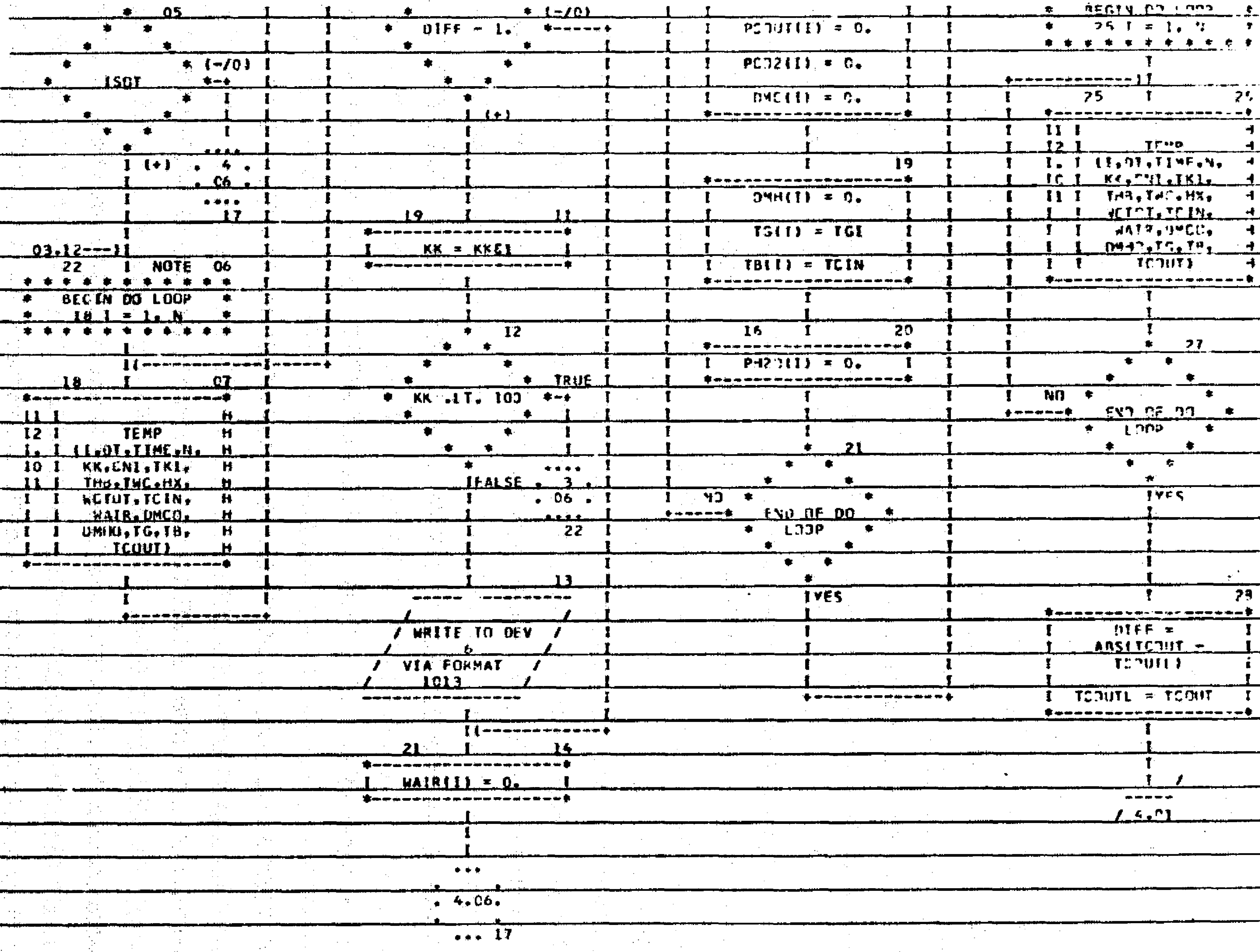
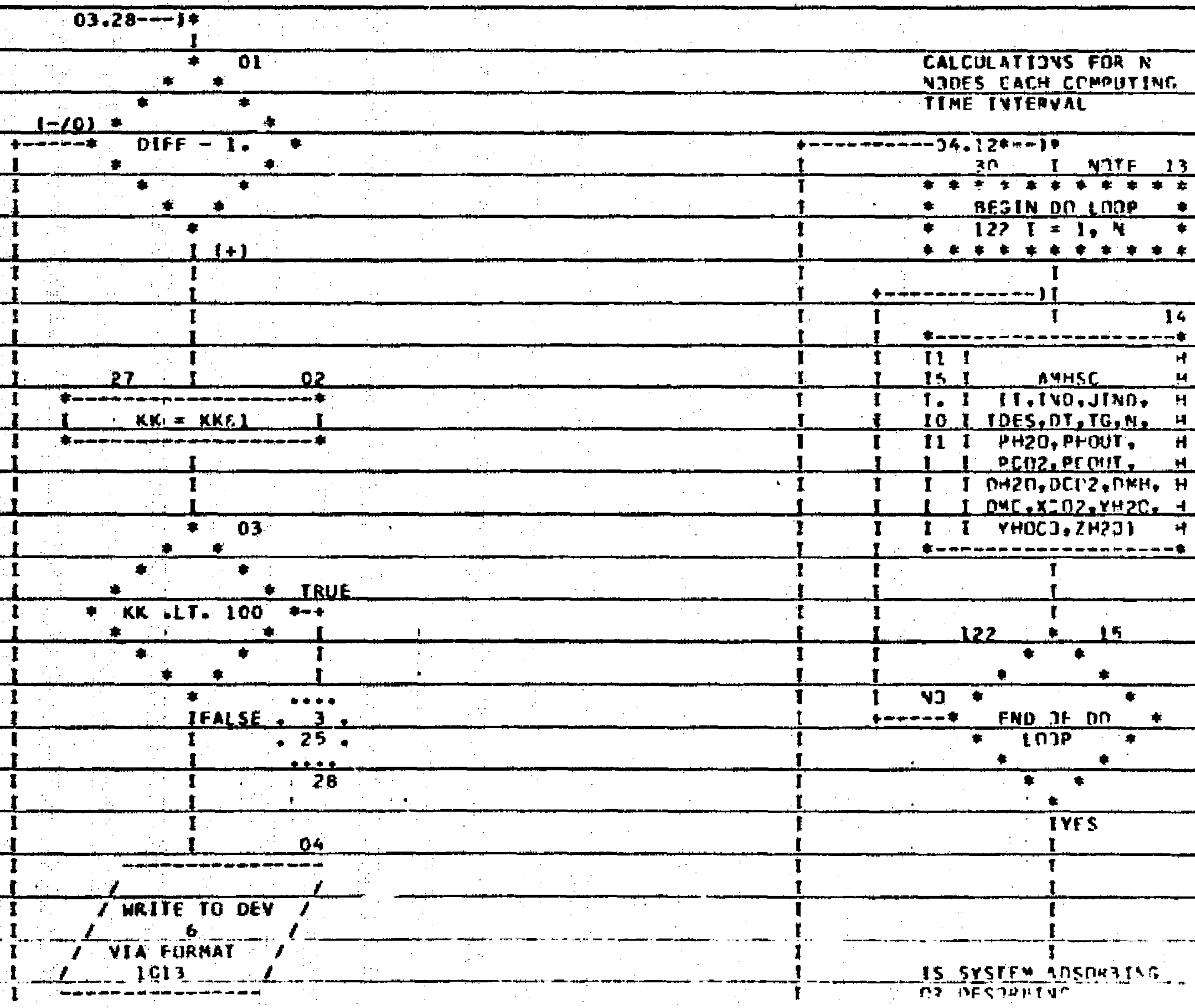

05
ISOT
(-/0)
(+)
4.06
17
03.12
22
NOTE 06
BEGIN DO LOOP
18 I = 1, N
18
07
TEMP
(I,DT,TIME,N,
KK,CNI,TKI,
THB,TWC,HX,
WCTUT,TCIN,
WAIR,DMCO,
DMHO,TG,TB,
TCOUT)
DIFF - 1.
(-/0)
(+)
19
11
KK = KK+1
12
KK .LT. 100
TRUE
FALSE
3.06
22
13
WRITE TO DEV 6 VIA FORMAT 1013
21
14
WAIR(I) = 0.
4.06
17
PCOUT(I) = 0.
PCO2(I) = 0.
DMC(I) = 0.
19
DMH(I) = 0.
TG(I) = TGI
TB(I) = TCIN
16
20
PH2O(I) = 0.
21
NO
END OF DO LOOP
YES
BEGIN DO LOOP
25 I = 1, N
25
25
TEMP
(I,DT,TIME,N,
KK,CNI,TKI,
THB,TWC,HX,
WCTUT,TCIN,
WAIR,DMCO,
DMHO,TG,TB,
TCOUT)
27
NO
END OF DO LOOP
YES
28
DIFF =
ABS(TCOUT -
TCOUTL)
TCOUTL = TCOUT
4.01

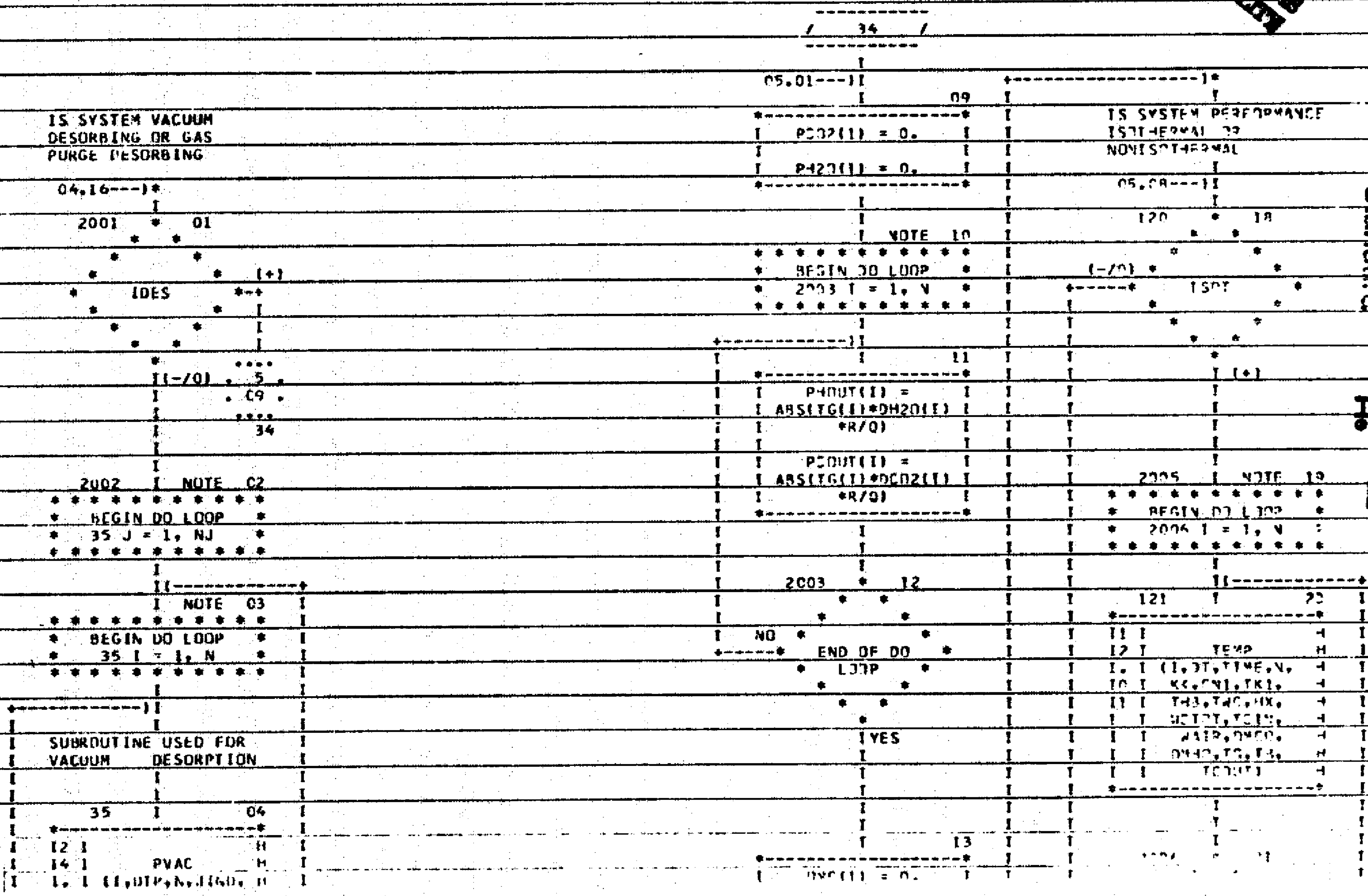
CHART TITLE - PROCEDURES



```
+--------------)I                                                       I                  I
   26      I  NOTE  05                                                  I                  I
* * * * * * * * * * * *                                                 I                  *   16
*     CONTINUE        *                                                 I               *     *
* * * * * * * * * * * *                                                 I            *           *
           I                                                            I         *                * (-/^)
           I                                                            I      *        IND          *-+
           I                      +--------------------)*               I         *                *   I
INITIAL CONDITIONS                I                     I               I            *           *     I
SET FOR EACH CASE                 I            20       *     10        I               *     *        I
           I                      I                  *     *            I                  *          ....
 03.05*--)I                       I               *           *         I                  I (+)    .  5  .
    17     I            06        I         NO  *               *       I                  I        . 14  .
*---------------------*           I      +-----*    END OF DO     *     I                  I          ....
I     MTH2O = 0.      I           I      I       *     LOOP     *       I                  I          2002
I                     I           I      I          *        *          I                  I
I     MTCO2 = 0.      I           I      I             *  *             I                  I
*---------------------*           I      I               *              I                  I
           I                      I      I               IYES           I                 ...
           I                      I      I               I              I              .       .
           I  NOTE  07            I      I               I              I              .  5.01 .
* * * * * * * * * * * *           I      I               I              I              .       .
*    BEGIN DO LOOP    *           I      I               I              I                 ...  2001
*     20 I = 1, N     *           I      I               I              I
* * * * * * * * * * * *           I      I               I          11  I
           I                      I      I         -------------------  I
           I(-------------I-------+        /                   /        I
           I            08        I      / WRITE TO DEV      /          I
*---------------------*           I     /        6          /           I
I      XCO2(I) =      I           I    /   VIA FORMAT     /             I
I ICXE/(100.*MCO2)    I           I   /       1005       /              I
I                     I           I  -------------------                I
I      YH2O(I) =      I           I               I                     I
I ICYH/(100.*MH2O)    I           I               I                     I
I                     I           I               I                     I
I     YHOCO(I) =      I           I               *      12             I
I ICYHC/(100.*MCO2)   I           I            *     *                  I
*---------------------*           I         *           *               I
           I                      I      *                 * (-/0)      I
           I                      I   *       TIME           *-+        I
           I            09        I      *                 *   I        I
*---------------------*           I         *           *      I        I
I      ZH2O(I) =      I           I            *     *         I        I
I ICZC/(100.*MH2O)    I           I               *           ....      I
*---------------------*           I               I (+)     .  5  .     I
           I                      I               I         . 23  .     I
           I                      I               I           ....      I
           /---------------+                      I           125       I
                                                  I                     I
                                                  I                     I
                                                  +---------------------+
```

Hamilton Standard U A

CHART TITLE - PROCEDURES



```
I1 I PIN,POUT,DMHO, H
I  I DMCO,PHO,PCO,  H
I  I TG,DMH,DMC,A,  H
I  I   EPS)         H
*--------------------*
          I
          *     05
       *     *
     *         *
NO *             *
----*  END OF DO   *
     *   LOOP    *
       *       *
         *   *
           *
          IYES
          I
          *     06
       *     *
     *         *
   *             *  NO
 *   END OF DO    *------
   *   LOOP      *
     *         *
        *   *
          *
          IYES
          I
          *-----------------------------)*
                                       I        08
                          *----------------------*
                          I  PHOUT(N) = PHO     I
                          I                     I
                          I  PCOUT(N) = PCO     I
                          I                     I
                          I  WAIR(I) = 0.       I
                          *----------------------*
                                       I
                                      ...
                                    . 5,18.
                                      ... 120
```

```
I    DMH(I) = 0.      I
*---------------------*
          I
04,16---)I
  2003    I  NOTE  14
* * * * * * * * * * * *
*   BEGIN DO LOOP     *
*   2004 I = 1, N     *
* * * * * * * * * * * *
          I
*-----------)I
    32    I         15
*---------------------*
I2 I                H
I7 I      PCAL      H
I. I  (I,DMC,DCO2,  H
I0 I  PCO2,PCOUT,   H
I1 I    DMCO)       H
*---------------------*
          I
          I
          I         16
*---------------------*
I2 I                H
I7 I      PCAL      H
I. I  (I,DMH,DH2O,  H
I0 I  PH2O,PHOUT,   H
I1 I    DMHO)       H
*---------------------*
          I
          I
          I
   2004   *    17
       *     *
     *         *
NO *             *
----*  END OF DO   *
     *   LOOP    *
       *       *
         *   *
           *
          IYES
          I
*-------------*
```

```
       *                 *
   *  END OF DO          *------*
     *   LOOP      *
       *         *
          *   *
            *
           IYES
            I
            I
            I
*------------)I
  2010    I  NOTE  22
* * * * * * * * * * * *
*      CONTINUE       *
* * * * * * * * * * * *
            I
            I
            I
CALCULATION OF OUTPUT
PARAMETERS
            I
04,12---)I
   125    I           23
*---------------------*
I2 I                H
I1 I      EDIT      H
I. I  (TIME,DT,N,   H
I0 I  WH2O,WZT,DMH, H
I2 I  YH2O,ZH2O,    H
I  I  APH2O,LTH2O,  H
I  I  LYH2O,LZH2,   H
I  I   EFFH)        H
*---------------------*
            I
            I
            I  /
          -----
          / 6,01
```

CHART TITLE - PROCEDURES

```
05.24---)*
        I            01
*--------------------*
I2 I                 H
I1 I     FOUT        H
I. I  (TIME,DT,N,    H
I0 I  MCO2,MZT,DMC,  H
I2 I  XCO2,YHUCO,    H
I  I  YCO2,LTCO2,    H
I  I  LXCO2,LYHC,    H
I  I     EFFC)       H
*--------------------*
        I
        I            02
*--------------------*
I  MTH2O = 0.        I
I                    I
I  MTCO2 = 0.        I
*--------------------*
        I
        I   NOTE   03
* * * * * * * * * * * *
*  BEGIN DO LOOP     *
*  135 I = 1, N      *
* * * * * * * * * * * *
        I
+-----------)I
I       I
I CALCULATION OF H2O
I MASS ON BED LBS(
I       I
I       I            04
I *--------------------*
I I    MTH2O =         I
I I MTH2O&APH2O(I)     I
I I   *MZ/100.         I
I *--------------------*
I       I
I       I
I CALCULATION OF CO2
I MASS ON BED LBS(
I       I
```

```
+------------------)*
                   I
                   *  09
               *       *
           *               *
TRUE *                         *
+------* PLOT .EQ. 0.    *
I          *               *
I              *       *
I                  *
I                  IFALSE
I                  I
I                  I
I                  *  10
I              *       *
I          *               *
I TRUE *                       *
I(----* MOD(M,NPLOT)    *
I          *  .NE. 0    *
I              *       *
I                  *
I                  IFALSE
I                  I
I                  I             11
I   *--------------------------*
I   I     K = K+1              I
I   I                          I
I   I PLTIME(K) = TIME         I
I   I                          I
I   I PLPCTL(K) = PCTL         I
I   I                          I
I   I    PLPHOT(K) =           I
I   I     PHOUT(K)             I
I   *--------------------------*
I                  I
I                  I             12
```

```
+------------------)*
                   I
                   *  16
               *       *
           *               *
FALSE *                        *
+------*  JIND .EQ. 1    *
I          *               *
I              *       *
I                  *
I                  ITRUE
I                  I
I                  I
I                  I
I                  I             17
I      ------------------
I     /                  /
I    / WRITE TO DEV     /
I   /       6          /
I  /  VIA FORMAT      /
I /      1033        /
I ------------------
I                  I
+------------)I
                   I             18
       ------------------
      / WRITE TO DEV    /
     /       6         /
    /  VIA FORMAT     /
   /      1001       /
  / FROM THE LIST   /
  ------------------
                   I
                   I   NOTE   19
* * * * * * * * * * * *
*  LIST = TIME,      *
*   PCTL, TCOUT,     *
*   EFFH, EFFC,      *
*   LTH2O, LTCO2,    *
*   LXH2O, LYH2,     *
*   LXCO2, LYHC      *
* * * * * * * * * * * *
                   I
```

```
+------------------)*
                   I             25
      ------------------
     /                  /
    / WRITE TO DEV     /
   /       6          /
  /  VIA FORMAT      /
 /      1015        /
 ------------------
                   I
                   I
                   I             25
      ------------------
     / WRITE TO DEV    /
    /       6         /
   /  VIA FORMAT     /
  /      1006       /
 / FROM THE LIST   /
 ------------------
                   I
                   I   NOTE   27
* * * * * * * * * * * *
*     LIST =         *
* (DMC(I),I = 1,N),  *
*     DMCO(N)        *
* * * * * * * * * * * *
                   I
                   I             28
      ------------------
     / WRITE TO DEV    /
    /       6         /
   /  VIA FORMAT     /
  /      1007       /
 / FROM THE LIST   /
 ------------------
                   I
                   I   NOTE   29
* * * * * * * * * * * *
*     LIST =         *
* (DMH(I),I = 1,N),  *
*     DMHO(N)        *
* * * * * * * * * * * *
                   I
```

Hamilton Standard

```
MTCO2 =
MTCO2&APCO2(I)
*MZ/100.

135   06

NO     END OF DO
       LOOP
       YES

CALCULATION OF TOTAL
BED LOADING  H2O AND
CO2)

                     07
PCTL =
(MTH2O&MTCO2)
*100./MZT

SET UP PRINTER PLOT
ARRAYS
```

```
PLPCOT(K) =
PCOUT(N)

PLMXC(K) = LTH2O

PLMYC(K) = LTCO2

PLMTYH(K) = TCOUT

                     13
PLMZH2(K) = TG(N)

-----06.09*--
140          14
*MOD(M,
 NPRINT)      TRUE
 .NE. 0 .AND.
 JIND .NE. 1
    FALSE    8
            16
           150

PRINT OUTPUT
VARIABLES
```

```
                  20
/ WRITE TO DEV  /
      6
/  VIA FORMAT  /
      1002

                  21
/ WRITE TO DEV  /
      6
/  VIA FORMAT  /
      1003
/ FROM THE LIST /

           NOTE  22
       LIST =
   (APCO2(I),I =
       1,N)

                  23
/ WRITE TO DEV  /
      6
/  VIA FORMAT  /
      1004
/ FROM THE LIST /

           NOTE  24
       LIST =
   (APH2O(I),I =
       1,N)
```

```
   BEGIN DO LOOP
   1002 I = 1,N

       1002            31
   DMO(I) =
   DMC(I)&DMH(I)

                   32
 NO     END OF DO
          1002
          YES

                       33
   DMOL =
   DMCO(N)&DMHO(N)

                       34
/ WRITE TO DEV  /
      6
/  VIA FORMAT  /
      1500
/ FROM THE LIST /

/ 7,01
```

CHART TITLE - PROCEDURES


```
     ------------                                                          -----------
    /   1027   /                                                          /   152    /
     ------------                                                          -----------
          I                                                                     I
  07,13---)I                                                +------------------)I
          I  NOTE  01                                       I                   I          21
* * * * * * * * * * * *    +-------------------)*           I          *--------------------*
*     CONTINUE        *    I                   I  NOTE  11  I          I2 I      ALOGIC      H
* * * * * * * * * * * *    I       * * * * * * * * * * * *  I          I0 I    (TIMEGDT,     H
          I                I       * LIST = (TG(I),I =  *   I          I. I  ADSORB,DESORP,  H
          I                I       *      1,N)          *   I          I0 I  IND,JIND,TMAX,  H
          I          02    I       * * * * * * * * * * * *  I          I1 I  PRLAST,NPRINT)  H
*---------------------*    I                   I            I          I  I                  H
I      PTAH =         I    I                   I            I          *--------------------*
I   (POUT*(PHAVG(N)   I    I                   I        12  I                   I
I      /(PHAVG(N)     I    I       -------------------      I          08,20---)I
I    &PCAVG(N))))     I    I      / WRITE TO DEV     /      I            163    I  NOTE  22
I                     I    I     /       6          /       I          * * * * * * * * * * * *
I      PTAC =         I    I    /   VIA FORMAT     /        I          *     CONTINUE         *
I   (POUT*(PCAVG(N)   I    I   /      1025        /         I          * * * * * * * * * * * *
I      /(PHAVG(N)     I    I  / FROM THE LIST    /          I                   I
I    &PCAVG(N))))     I    I  -------------------           I                   I
*---------------------*    I                   I            I                   I
          I                I                   I            I              RESET TIME
          I                I                   I  NOTE  13  I                   I
          I          03    I       * * * * * * * * * * * *  I                   I
     ------------------    I       * LIST = (TB(I),I =  *   I                   I          23
    / WRITE TO DEV    /    I       *      1,N)          *   I          *--------------------*
   /       6         /     I       * * * * * * * * * * * *  I          I  TIME = TIMEGDT    I
  /   VIA FORMAT    /      I                   I            I          *--------------------*
 /      1017       /       I                   I            I                   I
/ FROM THE LIST   /        I                   I            I                   I
------------------         I                   *    14      I                   I
          I                I                 *   *          I                   *     24
          I                I               *       *        I                 *   *
          I  NOTE  04      I    FALSE *  MOD(N,       *     I               *       *
* * * * * * * * * * * *    I    +-----*   2*NPRINT)    *    I      TRUE *IND .NE. 0 *
*   LIST = FACTC,     *    I    I      *   .EQ. 0     *     I      +-----*  .OR. JIND    *
*   (PCAVG(I),I =     *    I    I        *          *       I      I      *  .NE. 1    *
*     1,N), PTAC      *    I    I          *      *         I      I        *        *
* * * * * * * * * * * *    I    I              *            I      I          *    *
          I                I    I              ITRUE        I      I            *
          I                I    I              I            I      I            IFALSE
          I          05    I    I              I            I      I            I
     ------------------    I    I              I            I      I            I
    / WRITE TO DEV    /    I    I              I            I      I            I
   /       6         /     I    I              I            I      I            I
  /   VIA FORMAT    /      I    I              I        15  I      I            I
 /      1019       /       I    I       -------------------  I      I            I          25
/ FROM THE LIST   /        I    I      /                  /  I      I  *--------------------*
------------------         I    I     / WRITE TO DEV     /   I      I  I     OMC(I) =       I
          I                I    I                       /    I      I  I                    I
```

```
          I                I    I   / VIA FORMAT  /   I    I  I                   I
          I  NOTE  06      I    I  /    1033     /    I    I  I    DMH(I) =       I
* * * * * * * * * * * *    I    I  ----------------   I    I  I  PIH2O/(R*TGI)*2  I
*   LIST = FACTH,      *   I    I         I            I    I  *------------------*
*   (PHAVG(I),I =      *   I    +----06,14*--)I        I    I          I
*     1,N), PTAH       *   I       150    I  NOTE  15  I    +----------)I
* * * * * * * * * * * *    I    * * * * * * * * * * *  I           210   I  NOTE  26
          I                I    *     CONTINUE      *  I       * * * * * * * * * * *
          I                I    * * * * * * * * * * *  I       *      CONTINUE     *
          I         07     I              I            I       * * * * * * * * * * *
   ----------------        I              I            I                 I
   / WRITE TO DEV  /       I              I       17   I                 I
  /      6        /        I    *-------------------*  I                 I
 /   VIA FORMAT  /         I    I      M = M61      I  I                 *  27
/      1022     /          I    *-------------------*  I               *   *
/ FROM THE LIST /          I              I            I             *       *
----------------           I              I            I           *           * (-/0)
          I                I              I            I         *  TIME - TMAX  *--+
          I                I    SET UP INDICATORS FOR  I           *           *    I
          I  NOTE  08      I    ADSORB AND DESORB      I             *       *      I
* * * * * * * * * * * *    I    CYCLES                 I               *   *        I
*   LIST = PIN,        *   I              I            I                 *        ....
* (PT(I),I = 1,N),     *   I              I            I                 I (+)   . 4 .
*       POUT           *   I              I            I                 I       . 13 .
* * * * * * * * * * * *    I       160    *    18      I                 I        ....
          I                I           *     *         I                 I         30
07,23---)I                 I         *         *       I                 I
 1030     I         09     I       *             *  (+) I                I
   ----------------        I     *      TIME       *------+       220    I  NOTE  28
   /              /        I       *             *              * * * * * * * * * * *
   / WRITE TO DEV  /       I         *         *                *      CONTINUE     *
  /      6        /        I           *     *                  * * * * * * * * * * *
 /   VIA FORMAT  /         I              *                              I
/      1023     /          I              I(-/0)                         I
----------------           I              I                              I
          I                I              I                    PRINTER PLOT OUTPUT
          I                I              I                              I
          I         10     I              I                              I
   ----------------        I              I                              I
   / WRITE TO DEV  /       I       161    I       19                     I  /
  /      6        /        I    *-------------------*                  -----
 /   VIA FORMAT  /         I    I2 I                H                 / 9.01
/      1024     /          I    I0 I      ALOGIC    H
/ FROM THE LIST /          I    I. I (TIME,ADSORB,  H
----------------           I    IQ I  DESORB,IND,   H
          I                I    I1 I   JIND,TMAX,   H
          I                I    I  I PRLAST,NPRINT) H
          *----------------*    *-------------------*
                                          I
                                          I
                                          I  20
                                         ...
                                       .     .
                                       . 8.22.
                                       .     .
                                         ... 163
```

CR-115568
SVHSER-6040

CHART TITLE - PROCEDURES

```
             08.29---)*
                      I
                      *    01
                    *   *
                  *       *
                *           * (-/2)
              *    PLOT       *-+
                *           *   I
                  *       *     I
                    *   *       I
                      *        ....
                      I (+)   .  2 .
                      I       . 04 .
                      I        ....
                      I         10
                      I
                      I
               230    I         02
           *-----------------------*
           I  I                    H
           I  I      PPLOT         H
           I  I     (PLTIME,       H
           I  I     PLPCTL,K,      H
           I  I       ' * '        H
           I  I ,1,7,0,1,0.,  '    H
           I  I TOTALBEDLOADIN     H
           I  I   G ' ,500)        H
           *-----------------------*
                      I
                      I
                      I         03
           *-----------------------*
           I  I                    H
           I  I      PPLOT         H
           I  I (PLTIME,PLMXC,     H
           I  I     K, ' + '       H
           I  I ,1,7,0,1,0.,  '    H
           I  I TOTALH2OLOADIN     H
           I  I   G ' ,500)        H
           *-----------------------*
                      I
                      I
                      I         04
           *-----------------------*
           I  I                    H
           I  I      PPLOT         H
           I  I (PLTIME,PLMYC,     H
```

ORIGINAL PAGE IS OF POOR QUALITY

```
I  I ,1,7,0,1,0., ' H
I  I TOTALCO2LOADIN H
I  I   G ' ,500)    H
*-------------------*
          I
          I
          I          C5
*-------------------*
I  I                H
I  I     PPLOT      H
I  I    (PLTIME,    H
I  I   PLPHOT,K,    H
I  I     ' * '      H
I  I ,1,7,0,1,0., ' H
I  I OUTLETPARTIALP H
I  I RESSUREOFH2O ' H
I  I     ,500)      H
*-------------------*
          I
          I
          I          06
*-------------------*
I  I                H
I  I     PPLOT      H
I  I    (PLTIME,    H
I  I   PLPCOT,K,    H
I  I     ' * '      H
I  I ,1,7,0,1,0., ' H
I  I OUTLETPARTIALP H
I  I RESSUREOFCO2 ' H
I  I     ,500)      H
*-------------------*
          I
          I
          I          C7
*-------------------*    *-------------------I*
I  I                H    I                   I         D9
I  I     PPLOT      H    I            *-------------------*
I  I    (PLTIME,    H    I            I  I                H
I  I  PLMTYH,K, '   H    I            I  I     PPLOT      H
I  I     ( '        H    I            I  I    (PLTIME,    H
I  I ,1,7,0,1,0., ' H    I            I  I   PLMZH2,K,    H
I  I OUTLETCOOLANTT H    I            I  I     ' * '      H
I  I  EMPERATURE '  H    I            I  I ,1,7,0,1,0., ' H
I  I     ,500)      H    I            I  I OUTLETPROCESSG H
*-------------------*    I            I  I ASTEMPERATURE  H
          I              I            I  I   ' ,500)      H
          I              I            *-------------------*
          *--------------*                     I
                                               I
                                               I 10
                                              ...
                                             .   .
                                             . 2.04.
                                             .   .
                                              ... 10
```

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CHART TITLE - NON-PROCEDURAL STATEMENTS

```
REAL      KX     , KXR    , KY    , KYR    , KYH    , KYHR   , KZ     ,
 KZR    , ICXC   , ICYH   , ICZC   , ICYHC  , MZT    , MH2O   , MCO2   ,
 MTCO2  , LXCO2  , LYH2O  , LZH2   , LTH2O  , LTCO2, LYHC,
 MZ     , MTH2O  ,ISOT  ,IDES
DIMENSION     D 200(     , HOL  20(    , PCO2 100(   , PH2O 100(   ,
 DMC 100(    , DMH 100(   , XCO2 100(   ,  YH2O 100(  , YHOCO 100(  ,
 ZH2O 100(   ,
 XR 100(     , YR 100(    , YHCR 100(   , ZR 100(     ,
     DH2O 100(,PHOUT 100(,
 DMHO 100(   , DCO2 100(  , PCOUT 100(  , DMCO 100(
DIMENSION
 PLTIME 500(, PLPCTL 500(, PLPHOT 500(, PLPCOT 500(
DIMENSION PLMXC 500(, PLMYC 500(, PLMTYH 500(, PLMZH2 500(
DIMENSION APH2O 100(, APCO2 100(,CON 12(,C 5(
DIMENSION WAIR 100(,QR 100(,TB 100(,TG 100(,CN1 16(,
  TK1 20(, THB 20(, TWC 20(, HX 20(
EQUIVALENCE       D 1(,DT      (,  D 2(,TMAX    (,
  D 3(,PRINT    (,  D 4(,PLOT     (,  D 5(,FN       (,
  D 6(,AIND     (,  D 7(,IDES     (,  D 8(,ISOT     (,
  D 9(,XJ       (
EQUIVALENCE       D 11(,ICXC    (,  D 12(,ICYH    (,
  D 13(,ICZC    (,  D 14(,ICYHC   (,  D 15(,PIH2O   (,
  D 16(,PICO2   (
EQUIVALENCE       D 21(,XOL     (,  D 22(,YOL     (,
```

```
          D 26(,KY      (,  D 27(,KYR     (,  D 28(,KYH     (,
          D 29(,KYHR    (,  D 30(,KZ      (,  D 31(,KZR     (,
          D 32(,MZT     (,  D 33(,PAIR    (,  D 34(,Q       (,
          D 35(,TCIN    (,  D 36(,TGI     (,  D 37(,PIN     (,
          D 38(,POUT    (,  D 39(,ADSORB  (,  D 40(,DESORB  (,
          D 41(,C 1(    (,  D 45(,HCTOT   (,  D 46(,CV1 1( (
         EQUIVALENCE        D 101(,TK1 1((,  D 121(,THB 1((,
          D 141(,TWC 1((,  D 161(,HX 1((,  D 62(, PRLAST(
         ,  D 63(,A(,  D 64(,EPS(
         DIMENSION  PCAVG 100(, PHAVG 100(
         DIMENSION  DMO 100(, DTOT 100(, PT 100(, TFA 100(
         COMMON/BLOK3 /PCAVG,PHAVG
         COMMON/OUTPUT/PT, FACTH, FACTC
         COMMON/BLOK1/XR,YR,YHCR,ZR
         COMMON/BLOK2/CON
 1020    FORMAT 1H1, 20A4(
 1000    FORMAT @GINPUT@ /2X,
          8H DT     ,G12.6,8H TMAX    ,G12.6,8H PRINT   ,G12.6,
          8H PLOT   ,G12.6,8H FN      ,G12.6,8H IN3     ,G12.6/2X,
          8H IDES   ,G12.6,8H ISOT    ,G12.6,8H XJ      ,G12.6,
          8H ICXC   ,G12.6,8H ICYH    ,G12.6,8H ICZC    ,G12.6/2X,
          8H ICYHC  ,G12.6,8H PIH2O   ,G12.6,8H PICO2   ,G12.6,
```

CHART TITLE - NON-PROCEDURAL STATEMENTS


```
                8H XOL     ,G12.6,8H YOL     ,G12.6,8H ZOL     ,G12.6/2X,
                8H KX      ,G12.6,8H KXR     ,G12.6,8H KY      ,G12.6,
                8H KYP     ,G12.6,8H KYH     ,G12.6,8H KYHR    ,G12.6/2X,
                8H KZ      ,G12.6,8H KZR     ,G12.6,8H HZT     ,G12.6,
                8H PAIR    ,G12.6,8H Q       ,G12.6,8H TCIN    ,G12.6/(
         1016   FORMAT  2X,
                8H TGI     ,G12.6,8H PIN     ,G12.6,8H POUT    ,G12.6,
                8H ADSORB  ,G12.6,8H DESORB  ,G12.6,8H VB      ,G12.6/2X,
                8H XMU     ,G12.6,8H DIA     ,G12.6,8H WETOT   ,G12.6,
                8H CPC     ,G12.6,8H LB      ,G12.6,8H ABHXT   ,G12.6/2X,
                8H AAMBT   ,G12.6,8H WHX     ,G12.6,8H WBED    ,G12.6,
                8H CPHX    ,G12.6,8H CPBED   ,G12.6,8H AB      ,G12.6/2X,
                8H AHX     ,G12.6,8H KB      ,G12.6,8H KHX     ,G12.6,
                8H TAMB    ,G12.6,8H HAMB    ,G12.6,8H NPT1    ,G12.6/2X,
                8H NPT2    ,G12.6,8H PRLAST  ,G12.6,8H A       ,G12.6,8H EPS
                ,G12.6//(
         1013   FORMAT @OHX SUBROUTINE WILL NOT REACH SS@/(
         1005   FORMAT  1H1, @OUTPUT@,/(
         1001   FORMAT ///2X,
                      8H TIME    G12.6,8H PCTL    G12.6,8H TCOUT   G12.6,20X,
                      8H EFFH    G12.6,8H EFFC    G12.6/2X,
                      8H LTH2O   G12.6,8H LTCO2   G12.6,8H LYH2O   G12.6,8H LZH2
                G12.6,8H LXCO2   G12.6,8H LYHC    G12.6(
         1002   FORMAT @OWT PCT ADSORBED BY NODES@(
```

```
1004     FORMAT @  LT-20     @,13X,8G13.5(
1015     FORMAT @OFLOW RATE  LB-MOLES/MIN( BETWEEN NODES@(
1006     FORMAT @  CO2       @, 6X,8G13.5(
1007     FORMAT @  H2O       @, 6X,8G13.5(
1009     FORMAT @  TOTAL     @, 6X,8G13.5(
1010     FORMAT @ORATE OF ADSORPTION  LB-MOLES/MIN( BY NODES@(
1011     FORMAT @  CO2       @,13X,8G13.5(
1012     FORMAT @  H2O       @,13X,8G13.5(
1014     FORMAT @  TOTAL     @,13X,8G13.5(
1018     FORMAT @OPRESSURES BY NODE, INCLUDING BOTH ENDS  MM HG(@(
1017     FORMAT @  CO2       @,9G13.5(
1019     FORMAT @  H2O       @,9G13.5(
1022     FORMAT @  TOTAL     @,9G13.5(
1023     FORMAT @OTEMPERATURES  DEG F(@(
1024     FORMAT @  GAS       @,13X,8G13.5(
1025     FORMAT @  BED       @,13X,8G13.5(
1033     FORMAT @1@(
```

Hamilton Standard

CHART TITLE - SUBROUTINE TEMP(I,DT,TIME,N,JIND,CON,TKI,THB,TWC,HX,WCTOT,TCIN,WA

```
       ------------
     /   TEMP    /
       ------------

   03,07*--)*          +------------------)*          +------------------)*
                       I                  I      07    I                 I         15
  SIMULATION OF AN     I      *----------------*       I           ----------------
  AIR-AIR CROSSFLOW    I      I  K3 = KB*AB/DEL I      I         / WRITE TO DEV  /
  HEAT EXCHANGER       I      I                 I      I        /       6       /
  SET VALUES FOR       I      I K4 = KHX*AHX/DELL I    I       /   VIA FORMAT  /
  CONSTANTS DURING     I      I                 I      I      /      1012     /
  FIRST PASS           I      I   WC = WCTOT/N  I      I     / FROM THE LIST /
                       I      I                 I      I     ----------------
          *            I      I  ABHX = ABHXT/N I      I                I
          I            I      *-----------------*      I                I
          *   01       I               I               I                I  NOTE  16
       *     *         I               I               I     * * * * * * * * * * *
     *          *      I               I        08     I     *      LIST =        *
   *              *  (+) I     *-----------------*      I     *   (THB(J),J =      *
 *      JIND       *--+  I     I  AAMB = AAMBT/N I      I     *     1,NPT1)        *
   *              *   I  I     I                 I      I     * * * * * * * * * * *
     *          *     I  I     I ACHX = ABHX&AAMB I     I                I
       *     *        I  I     I                 I      I                I
          *        ....  I     I MCHX = WHX*CPHX/N I    I                I         17
          I(-/0) . 12 .  I     I                 I      I            ----------------
          I      . 22 .  I     I      MCB =      I      I           /               /
          I        ....  I     I  WBED*CPBED/N   I      I          / WRITE TO DEV  /
          I         10   I     *-----------------*      I         /       5       /
          I              I               I              I        /  VIA FORMAT   /
          I              I               I              I       /     1013      /
          I              I               I  NOTE  09    I      ----------------
    1     *   02         I     * * * * * * * * * * *    I                I
       *     *           I     *   BEGIN DO LOOP   *    I                I
     *          *        I     *    2 J = 1, N     *    I                I         18
   *              *  (+) I     * * * * * * * * * * *    I            ----------------
 *      I - 1      *--+  I               I              I          / WRITE TO DEV  /
   *              *   I  I   +-----------)I             I         /       6       /
     *          *     I  I   I           I        10    I        /   VIA FORMAT  /
       *     *        I  I   I     *-----------------*  I       /      1012     /
          *        ....  I   I     I  THX(J) = TG(J) I  I      / FROM THE LIST /
          I(-/0) . 12 .  I   I     I                 I  I      ----------------
          I      . 22 .  I   I     I   TB(J) = TG(J) I  I                I
          I        ....  I   I     *-----------------*  I                I
          I         10   I   I               I          I                I  NOTE  19
          I              I   I               I          I     * * * * * * * * * * *
          I              I   I               I          I     *      LIST =        *
    3     I         03   I   I       2       *     11   I     *   (TWC(J),J =      *
 *-----------------------*   I           *       *      I     *     1,NPT2)        *
 I   CPC = CON(1)      I I   I        *             *   I     * * * * * * * * * * *
 I                     I I   I  NO  *                 * I                I
 I    LB = CON(2)      I I   +------*   END OF DO     * I                I
```

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```
I  ABHXT = CON(3)   I
I                   I
I  AAM2T = CON(4)   I
I                   I
I  WHX = CON(5)     I
*-------------------*
          I
          I
          I         C5
*-------------------*
I  WBED = CON(6)    I
I                   I
I  CPHX = CON(7)    I
I                   I
I  CPBED = CON(8)   I
I                   I
I  AB = CON(9)      I
*-------------------*
          I
          I
          I         05
*-------------------*
I  AHX = CON(10)    I
I                   I
I  KB = CON(11)     I
I                   I
I  KHX = CON(12)    I
I                   I
I  TAMB = CON(13)   I
*-------------------*
          I
          I
          I         C6
*-------------------*
I  HAMB = CON(14)   I
I                   I
I  NPT1 = CON(15)   I
I                   I
I  NPT2 = CON(16)   I
I                   I
I  DELL = LB/N      I
*-------------------*
          I
          I
          *--------------*
```

```
            *     *
             *   *
               *
              IYES
               I
               I
               I
               I
               I
WRITE HEAT EXCHANGER
INPUT
               I
               I
               I          12
     ----------------
    /                /
   / WRITE TO DEV   /
  /       6        /
 /   VIA FORMAT   /
/       1011     /
 ----------------
               I
               I
               I          13
     ----------------
    / WRITE TO DEV  /
   /       6       /
  /   VIA FORMAT  /
 /       1012    /
/ FROM THE LIST /
 ---------------
               I
               I
               I  NOTE  14
* * * * * * * * * * * * *
*       LIST =          *
*     (TK1(J),J =       *
*       1,NPT1)         *
* * * * * * * * * * * * *
               I
               I
               *--------------*
```

```
     ----------------
    / WRITE TO DEV  /
   /       6       /
  /   VIA FORMAT  /
 /      1012     /
/ FROM THE LIST /
 ---------------
          I
          I
          I  NOTE  21
* * * * * * * * * * * * *
* LIST = (HX(J),J =     *
*       1,NPT2)         *
* * * * * * * * * * * * *
          I
12,01*--I
   10     I  NOTE  22
* * * * * * * * * * * * *
*       CONTINUE        *
* * * * * * * * * * * * *
          I
          I
          I
CALCULATE CONSTITUENT
WEIGHT FLOW
          I
          I
          I         23
*---------------------*
I     WCO2(I) =       I
I   DMCO2(I)*44.      I
I                     I
I     WH2O(I) =       I
I   DMH2O(I)*18.      I
*---------------------*
          I
          I
          I
CALCULATE HEAT OF
ADSORPTION
          I
          I
          *---------------*
```

```
*-----------------------------)*
                I                 25
*---------------------------*
I        O2(I) =            I
I        DMHO(I)            I
I   *1400.+DMCO2(I)         I
I        *1400.             I
I                           I
I        K1 =               I
I   WAIR(I)+WCO2(I)         I
I        +WH2O(I)           I
*---------------------------*
                I
                I
                I
                *     26
             *     *
          *           *     TRUE
      *   K1 .EQ. 0.   *--*
          *           *   I
             *     *      I
                *       ....
             IFALSE  .  13  .
                I       . 21 .
                I       ....
                I        11
                I
                I
                I        27
*---------------------------*
I        K2 =               I
I     (WAIR(I)              I
I   *.24+WCO2(I)            I
I  *.2+WH2O(I)*.44)         I
I        /K1                I
*---------------------------*
                I
                I
                I
               ...
              .13.22.
               ... 12
```

Hamilton Standard

CHART TITLE - SUBROUTINE TEMP(I,DT,TIME,N,JIND,CON,TK1,THB,TWC,HX,WCTOT,TCIN,WA

```
             -----------
            /    11    /
            ------------
                 I
   12.26---)I
                 I            01
   *-----------------------*
   I      K2 = 0.          I
   *-----------------------*
                 I
   12.27---)I
         12      I            02
   *-----------------------*
   I   K11 = ABS(K1)       I
   *-----------------------*
                 I
                 I
                 I
                 *    03
              *     *
           *           *
 FALSE  *                 *
+------*    I .EQ. 1        *
I        *                 *
I          *             *
I             *       *
I                 *
I                 ITRUE
I                 I
I                 I
I                 I
I                 I
I                 I            04
I   *-----------------------*     +--------------------)*
I   I     TGI = TG(I)       I     I                     I           10
I   *-----------------------*     I        *---------------------------*
I                 I               I        I  I                        H
+--------------)I                 I        I  I        UNLIN           H
                  I               I        I  I  (NPT2,TWC,HX,         H
   OBTAIN HEAT TRANSFER           I        I  I    WC,HXX,IOF)         H
   COEFFICIENT BETWEEN            I        I  I                        H
   BED AND HEAT                   I        *---------------------------*
   EXCHANGER AS                   I                     I
   A FUNCTION OF WEIGHT           I                     I
   FLOW THROUGH BED               I                     I
                  I               I                     *     11
                  I               I                  *     *
        20        I           05  I               *           *        +--------------------)*
   *-----------------------*      I       FALSE  *                 *   I              21    I        16
   I  I                    H      I       +------*   IOF .NE. 0      *  I             *----------------------*
```

```
(NPT1,TK1,THB,
 K11,HB,IUF)

        06
 FALSE  IUF .NE. 0
        TRUE
                    07
 / WRITE TO DEV 6 VIA FORMAT 1000 FROM THE LIST /

        NOTE  08
 * LIST = IUF *

 OBTAIN HEAT TRANSFER
 COEFFICIENT BETWEEN
 HEAT EXCHANGER AND
 AMBIENT AS A FUNCTION
 OF COOLANT FLOW RATE


        TRUE
                    12
 / WRITE TO DEV 6 VIA FORMAT 1001 FROM THE LIST /

        NOTE  13
 * LIST = IUF *

        14
 K11 .EQ. 0.    TRUE
        FALSE
                    15
 A =
 HB*ABHX/(K11*K2)

 AA = EXP(-A)


 CALCULATION OF HEAT
 FLOW FROM PROCESS GAS
 TO BED

 22                 17
 Q1 = (TG1 -
   T3(I))
 *K1*K2*(1. - AA)

   UBHX =
 HB*HXX/(HBSHXX)

 CALCULATION OF HEAT
 FLOW FROM HEAT
 EXCHANGER TO BED
                    18
   Q2 =
 UBHX*ABHX*(THX(I)
   - T3(I))

        19
   I - 1     (-/0)
   (+)

 .14.01.
 ... 30


 52                 22
   Q3 = 0.
   Q7 = 0.

 14.02---
 50     21
   I - N     (-)
   (0/+)     . 14 .
             . 23 .
               52

 .14.05.
 ... 70
```

CHART TITLE - SUBROUTINE TEMP(I,DT,TIME,N,JIND,CON,TKI,THB,THC,HX,WCTOT,TCIN,WA


```
                                              -----------
                                             /    70    /
                                              -----------
                                                   I
                                          13.21---)I
                                                   I          05
CALCULATION OF NODAL                      *-------------------*
CONDUCTIVE HEAT FLOW                      I      Q4 = 0.      I
IN BED                                    I                   I
                                          I      Q8 = 0.      I
 13.19---)*                               *-------------------*
    30    I        01                              I
*-------------------*    *-----------------------)I
I  Q3 = K3*(TB(I -  I    I           8C     I  NOTE  06
I    1) - TB(I))    I    I       * * * * * * * * * * * *
*-------------------*    I       *      CONTINUE      *
          I              I       * * * * * * * * * * * *
          I              I                 I
          I              I                 I
CALCULATION OF NODAL     I                 I
CONDUCTIVE HEAT FLOW     I       CALCULATE BED
IN HEAT EXCHANGER        I       TEMPERATURE AND
          I              I       PROCESS GAS
          I              I       TEMPERATURE
          I        02    I                 I
*-------------------*    I                 I
I Q7 = K4*(THX(I -  I    I                 I          07
I   1) - THX(I))    I    I       *-------------------*
*-------------------*    I       I     TB(I) =       I
          I              I       I      TB(I)        I
          I              I       I   &(Q1&Q2&QR(I)   I
          I              I       I  &Q3&Q4)*DT/MCB   I
         ...             I       I                   I
       .     .           I       I     TG(I) =       I    *-------------------)*
      .13.21.            I       I  TB(I)&(TGI -     I    I                    I
       .     .           I       I    TB(I))*AA      I    I                    *    12
        ... 50           I       I                   I    I                 *     *
                         I       I  TGI = TG(I)      I    I              *           *
                         I       *-------------------*    I        (-) *               *
                         I                 I              I    *------*      I - N        *
                         I                 I              I    I       *                 *
                         I                 I          08  I    I          *           *
                         I       *-------------------*    I    I             *     *
                         I       I       B =         I    I    I                *
                         I       I HXX*ACHX/(WC*CPG) I    I    I                I(0/+)
                         I       *-------------------*    I    I                I
                         I                 I              I    I                I
                         I                 I              I    I                I
CALCULATION OF NODAL     I                 I              I    I                I
CONDUCTIVE HEAT FLOW     I       CALCULATION OF           I    I                I
IN BED                   I       HEAT FLOW FROM COOLANT   I    I      100       I        13
```

```
13.21---I*
60          03
Q4 =
K3*(TB(I&1) -
TB(I))

CALCULATION OF NODAL
CONDUCTIVE HEAT FLOW
IN HEAT EXCHANGER

            04
Q8 =
K4*(THX(I&1) -
THX(I))
```

```
            09
Q5 = WC*CPC*(1. -
EXP(-B))*(TCIN -
THX(I))

UAMB =
HXX*HAMB/(HXX&
HAMB)

CALCULATION OF HEAT
FLOW FROM AMBIENT TO
HEAT EXCHANGER

            10
Q6 =
UAMB*AAMB*(TAMB -
THX(I))

CALCULATE HEAT
EXCHANGER AND COOLANT
OUTLET TEMPERATURES

            11
THX(I) =
THX(I)&(Q5 -
Q2&Q3&Q4&Q6&Q7&Q8)
*DT/MCHX

TCOUT(I) =
THX(I)&(TCIN -
THX(I))*EXP(-B)
```

```
TOUT1 = 0.

            NOTE 14
* * * * * * * * * * *
*   BEGIN DO LOOP   *
*   105 I = 1, N    *
* * * * * * * * * * *

            15
TOUT1 =
TOUT1&TCOUT(I)

105     16
      *      *
   *            *   NO
*   END OF DO     *------
   *   LOOP     *
      *      *
         *
         I YES

CALCULATION OF
COOLANT OUTLET
TEMPERATURE

            17
TOUT = TOUT1/N

110     NOTE 18
* * * * * * * * * * *
*     CONTINUE      *
* * * * * * * * * * *

        19
  *  EXIT  *
```

CHART TITLE - NON-PROCEDURAL STATEMENTS


```
      REAL     L8     , K1     , K2     , K3     , MCR    , K4     , MCHX   ,
        KB,  KHX ,K11
      DIMENSION     WAIR 100(  , WC02 100(  , WH20 100(  , TK1  20(,
       THB  20(    , TWC  20(   , HX  20(     , Q3 100(     , T8 100( ,
                 TBPRIM 100(, THXPRM 100(, TCOUT 100(,
       THX 100(, CON 16(, TG 100(, DMCO 100(, DMHO 100(
 1011 FORMAT @OHB#F K1( TABLE@(
 1012 FORMAT 1X,10G12.6(
 1013 FORMAT @CHHX#F WC( TABLE@(
 1000 FORMAT @OK1 OFF TABLE - 10F#@,I1(
 1001 FORMAT  @OWC OFF TABLE - 10F#@,I1(
```

CHART TITLE - SUBROUTINE AMHSC(I,IND,JIND,IDES,DT,T,N,PH2O,PHOUT,PCO2,PCOUT,DH2

```
                -----------
               /  AMHSC   /
               -----------
                    I
         04.14---)I
                    I          01
         *--------------------*
         I    MZ = MZT/N      I
         I                    I
         I    MH2O = 18.      I
         I                    I
         I    MCO2 = 44.      I
         *--------------------*
                    I
                    I
                    I
         CONVERT ULTIMATE
         CAPACITY FROM PERCENT
         TO LB-MOLES/LB
                    I
                    I
                    I          02
         *--------------------*
         I        XO =        I
         I XOL/(100.*MCO2)    I
         I                    I
         I        YO =        I
         I YOL/(100.*MH2O)    I
         I                    I
         I        ZO =        I
         I ZOL/(100.*MH2O)    I
         I                    I
         I     YH2O(I) =      I
         I    TYH2O(I) -      I
         I     YHOCO(I)       I
         *--------------------*
                    I
                    I
                    I
                    *    03
                 *     *
              *           *
            *               *  TRUE
          * JIND .EQ. - 1    *-+
            *               *  I
              *           *    I
                 *     *       I
                    *        ....
                    IFALSE . 17 .
                    I      . 01 .
                    I      ....
```

```
                    I
                    I
                    I
                    *   04
                  *   *
                *       *
         I04  *           *
       +-----*  INU - JIND   *
       I      *           *
       I        *       *
       I          *   *
       I            *
       I            I(-/+)
       I            I
       I            I
       I            I
       I            I
       I            I
       I            I
       I      2     *    05
       I          *   *
       I        *       *
       I      *           * (-/0)
       I    *     IDES      *-+
       I      *           *   I
       I        *       *     I
       I          *   *       I
       I            *        ....
       I            I (+)   . 17 .
       I            I       . 06 .
       I            I        ....
       I            I          7
       I            I
       +----I6.04*--)I
            I       I       06    +-------------------)*
         *-------------------*    I                    I
         I    PCAVG(I) =     I    I        CALCULATE AVERAGE
         I (PCO2(I)&PCOUT(I) I    I        NODE PARTIAL
         I      )/2.         I    I        PRESSURES IF NOT ON
         *-------------------*    I        VACUUM DESORPTI
                    I             I                    I
                    I             I                    I
                    +-------------+                    I      07
                                          *-------------------*
                                          I     PHAVG(I) =    I
                                          I (PH2O(I)&PHOUT(I) I
                                          I       )/2.        I
                                          *-------------------*
                                                       I
                                                       I
                                                       I
                                                      ...
                                                     .   .
                                                     .17.06.
                                                     .   .
                                                      ... 7
```

CHART TITLE - SUBROUTINE AMHSC(I,IND,JIND,IDES,DT,T,N,PH2O,PHOUT,PCO2,PCOUT,OH2

```
              ------------
             /    3      /
             ------------
                  I
       16.03---)I
                  I
                  *    01
                *   *
              *       *
            *           *   TRUE
          *   I .GT. 1    *--+
            *           *    I
              *       *      I
                *   *        I
                  *         ....
                  IFALSE  . 16 .
                  I       . 06 .
                  I         ....
                  I            1
                  I
                  I
         6        I   NOTE  02
      * * * * * * * * * * * *
      *    BEGIN DO LOOP     *
      *    6 J = 1, 100      *
      * * * * * * * * * * * *
                  I
  +------------)I
  I               I         03
  I   *---------------------*
  I   I    PCAVG(J) =       I
  I   I (PCO2(J)&PCCUT(J)   I
  I   I        )/2.         I
  I   *---------------------*
  I               I
  I               I
  I       6       I         04
  I   *---------------------*
  I   I     PHAVG(J) =      I
  I   I (PH2O(J)&PHOUT(J)   I
  I   I        )/2.         I
  I   *---------------------*
  I               I
  I               I
  I               I
  I               *    05
  I             *   *
  I           *       *
  I  NO     *           *
  +------*    END OF DO    *
            *   LOOP     *
```

```
              LIMITING H2O
              ADSORPTION RATE
+------------------)*
I                   I
I          5        *     09
I                 *   *
I               *       *
I     (-/2)   *           *
I     +-----* YR(I)S/R(I) - *
I     I       * DMH(I)/MZ  *
I     I         *       *
I     I           *   *
I     I             *
```

```
YES

CALCULATE NODAL
ADSORPTION RATES FOR
EACH CONSTITUENT AT
EACH SIT

16.05*--)

7                06
XR(I) =
KX*PCAVG(I)*(XO -
XCO2(I)) -
KXR*XCO2(I)

YR(I) =
KY*PHAVG(I)*(YO -
(YH2O(I)) -
KYR*YH2O(I)

                 07
YHCR(I) =
YH2O(I)
*KYH*PCAVG(I) -
YHOCO(I)*KYHR

ZR(I) =
KZ*PHAVG(I)*(ZO -
ZH2O(I)) -
KZR*ZH2O(I)

        08
(-/0)
IND
(+)

.18.01.
... 53

20                 10
YR(I) =
(YR(I)/(YR(I)
&ZR(I)))*DMH(I)
/MZ

ZR(I) =
DMH(I)/MZ - YR(I)

LIMITING CO2
ADSORPTION RATE

30         11
XR(I)       (-/0)
EYHCR(I) -
DMC(I)/MZ

(+)    .10.
       .07.
        60

52                 12
XR(I) =
(XR(I)/(XR(I)
&YHCR(I)))*DMC(I)
/MZ

YHCR(I) =
DMC(I)/MZ - XR(I)

.18.07.
... 60
```

Hamilton Standard U A

CHART TITLE - SUBROUTINE AMHSC(I,IND,JIND,TUES,DT,T,N,PH2O,PHOUT,PCO2,PCOUT,DH2

```
                    ------------
                   /    53     /
                   ------------
                         I
              17.08---)I
                         I            01
            *-----------------------*
            I         DUM =          I
            I  (YH2O(I)&ZH2O(I)      I
            I          )/DT          I
            *-----------------------*
                         I
                         I
                         I
                         *     02
                       *   *
                     *       *
         (0/+)     *           *
      *------*    DUM&YR(I)      *
      I        *   &ZP(I)      *
      I          *           *
      I            *       *
      I              *
      I              I (-)
      I              I
      I              I
      I              I
      I              I
      I              I
      I        54    I            03
      I     *-----------------------*
      I     I        ZR(I) =         I
      I     I   ZR(I)/(YR(I)         I
      I     I     &ZR(I))*DUM        I
      I     I                        I
      I     I    YR(I) = DUM -       I
      I     I        ZR(I)           I
      I     *-----------------------*
      I              I
      *-----------)I
               55    I            04
            *-----------------------*
            I         DUM =          I
            I  (XCO2(I)&YHCCO(I)     I
            I          )/DT          I
            *-----------------------*
                         I
                         I
                         I
                         *     05
```

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U
A

```
              (0/+) *                 *
              +-----*    DUM&XR(I)      *
              I        * &YHCR(I)    *
              I          *         *
              I             *    *
              I               *
              I               I (-)
              I               I
              I               I
              I               I
              I               I
              I               I
              I      56       I           C6
              I   *-------------------------*
              I   I        XR(I) =          I
              I   I     XR(I)/(XR(I)        I    +-------------------I*
              I   I     &YHCR(I))*DUM       I    I                   I          09
              I   I                         I    I          *-------------------------*
              I   I   YHCR(I) = DUM -       I    I          I      XCO2(I) =          I
              I   I        XR(I)            I    I          I  XCO2(I)&XR(I)*DT       I
              I   *-------------------------*    I          I                         I
              I               I                  I          I      TYH2O(I) =         I
              +-----[7,1]*--)I                   I          I  TYH2O(I)&YR(I)*DT      I
                     60      I   NOTE   07       I          I                         I
                  * * * * * * * * * * * *        I          I      YHOCO(I) =         I
                  *       CONTINUE        *      I          I  YHOCO(I)&YHCR(I)       I
                  * * * * * * * * * * * *        I          I          *DT            I
                              I                  I          *-------------------------*
                              I                  I                   I
                              I                  I                   I
                  CALCULATION OF                 I                   I          10
                  LB-MOLE/NODE OF                I          *-------------------------*
                  ADSORBATES ON EACH             I          I      ZH2O(I) =          I
                  SITE                           I          I  ZH2O(I)&ZR(I)*DT       I
                              I                  I          I                         I
                              I                  I          I      YH2O(I) =          I
                              +------------------+          I     TYH2O(I) -          I
                                                            I      YHOCO(I)           I
                                                            I                         I
                                                            I      DH2O(I) =          I
                                                            I  (YR(I)&ZR(I))*MZ       I
                                                            *-------------------------*
                                                                     I
                                                                     I
                                                                     I          11
                                                            *-------------------------*
                                                            I      DCO2(I) =          I
                                                            I   (XR(I)&YHCR(I))       I
                                                            I         *MZ             I
                                                            *-------------------------*
                                                                     I
                                                                     I
                                                                     I 12
                                                                 ---------
                                                                *  EXIT   *
                                                                 ---------
```

CR-115568
SVHSER-6040

D-122

CHART TITLE - NON-PROCEDURAL STATEMENTS

C-4

```
REAL KX,KXR,KY,KYR,KYH,KYHR,KZ,KZR,MZ,MZT,MCO2,MH2O
COMMON/BLOK1/XR,YR,YHCR,ZR
COMMON/BLOK3/PCAVG,PHAVG
COMMON/BLOK2/CON
DIMENSION PH2O 100(,PHOUT 100(,PCO2 100(,PCOUT 100(,DH2O 100(,
          DCO2 100(,DMH 100(  ,DMC 100( ,XCO2 100( ,YH2O 100(,
        YHOCO 100( ,ZH2O 100( ,XR 100(  ,YR 100(   ,YHCR 100(,
            ZR 100(,CON 12(,TYH2O 100(,PHAVG 100(,PCAVG 100(,
 T 100(
EQUIVALENCE   CON 1(,XOL  (, CON 2(,YOL  (, CON 3(,ZOL  (,
 CON 4(,KX  (, CON 5(,KXR  (, CON 6(,KY   (, CON 7(,KYR  (,
 CON 8(,KYH (, CON 9(,KYHR (, CON 10(,KZ  (, CON 11(,KZR (,
 CON 12(,MZT(
```

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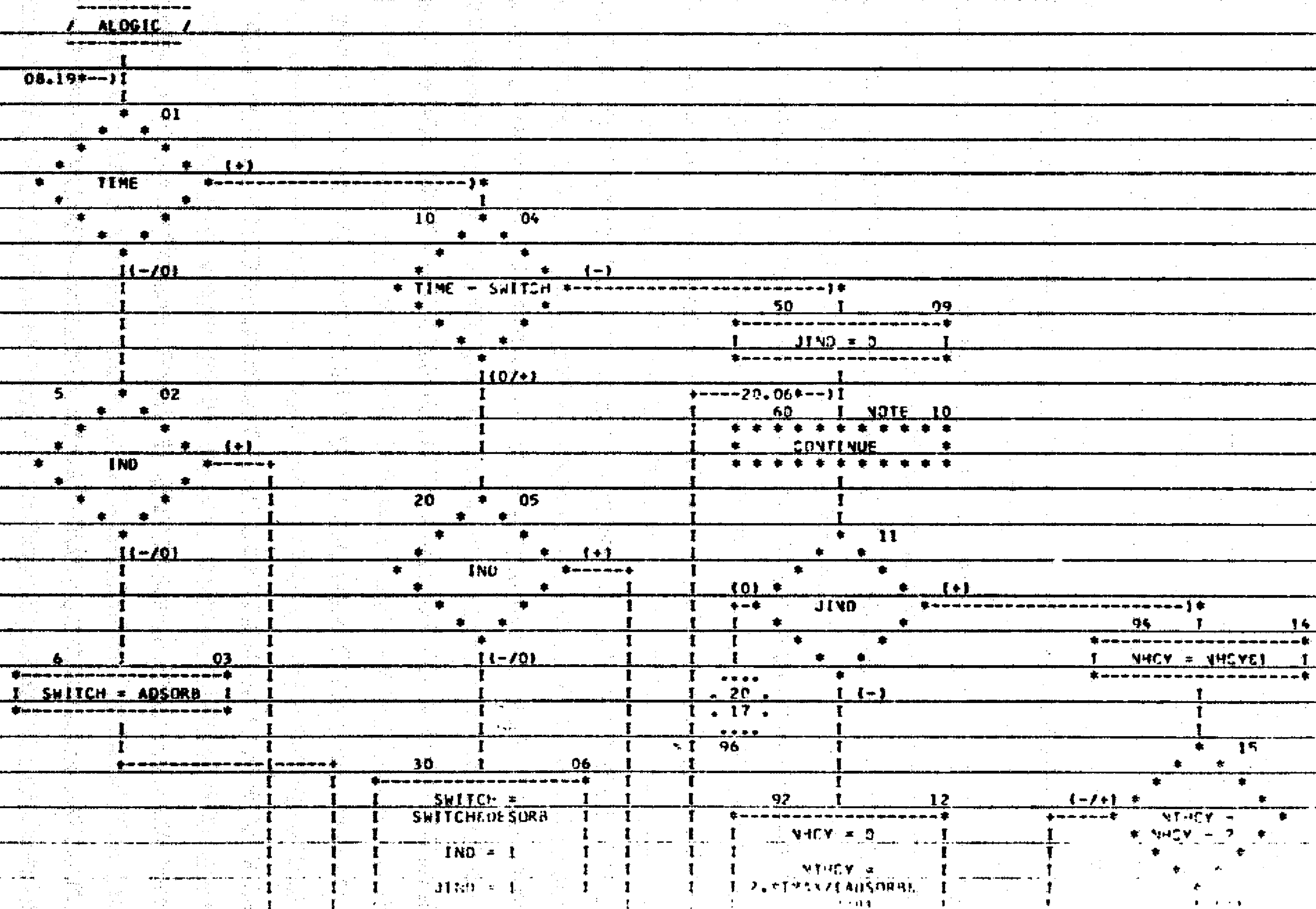
CHART TITLE - SUBROUTINE ALOGIC(TIME,ADSORB,DESORB,IND,JIND,TMAX,PRLAST,NPRINT)



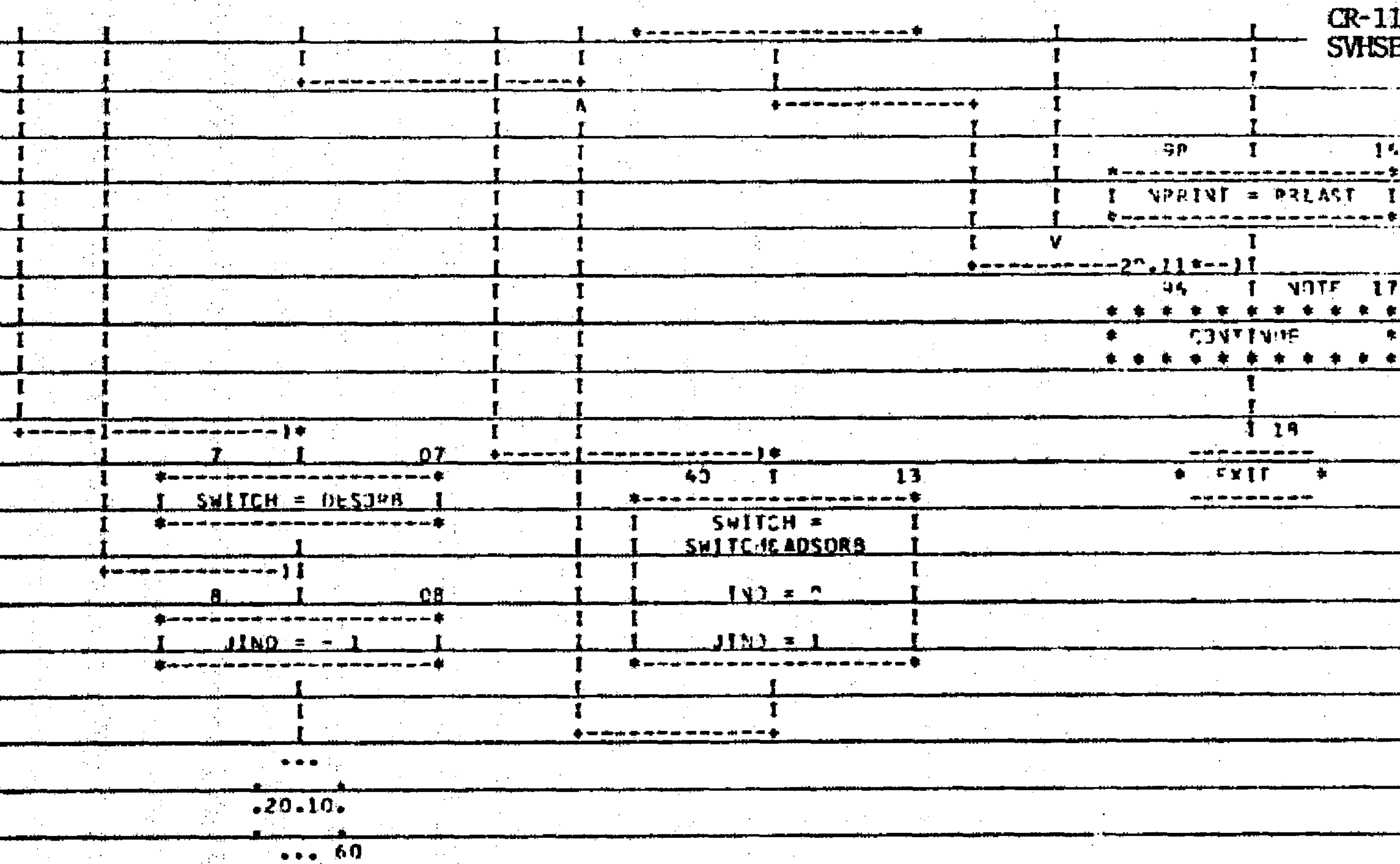
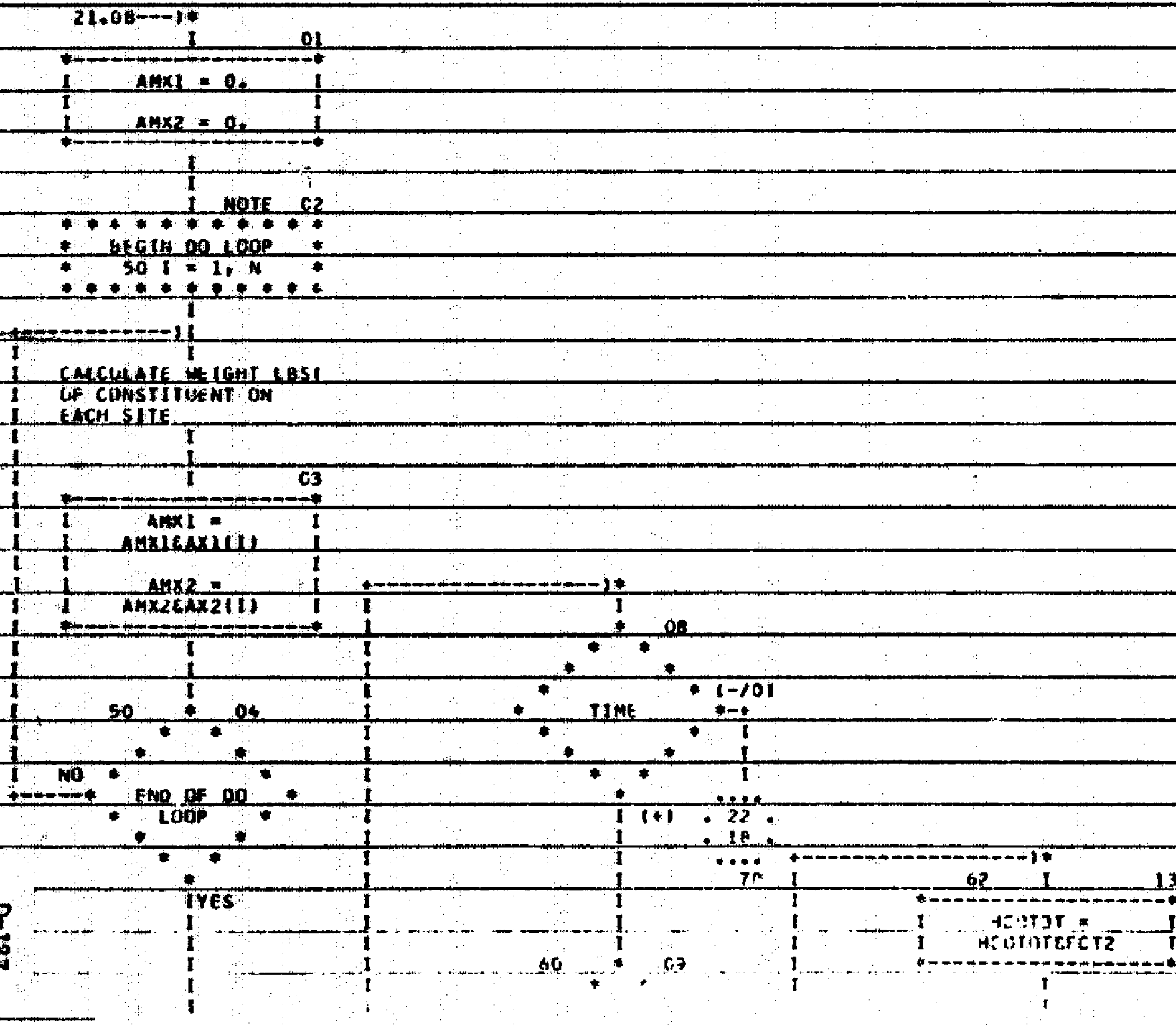

A
NPRINT = PRLAST
NOTE 17
CONTINUE
EXIT
SWITCH = DESORB
JIND = - 1
SWITCH = SWITCHEADSORB
JIND = 1
20.10.
60

CHART TITLE - SUBROUTINE FOUT(TIME,DT,N,MOLWT,MZT,DMH,X1,X2,LTOT,PCTL,PCM1,PCM2

```
                    ------------
                   /   FOUT    /
                   ------------
                         I
               05.23*--)I
                         I
                         *    02
                      *     *
                   *           *
             (+) *               *
        *------*      TIME         *
        I        *               *
        I          *           *
        I             *     *
        I                *
        I                I(-/0)
        I                I
        I                I
        I                I
        I                I
        I                I
        I        10      I          03
        I   *-----------------------*
        I   I    H2OTOT = 0.        I
        I   I                       I
        I   I    HCOTOT = 0.        I
        I   I                       I
        I   I    EFF = 100.         I
        I   I                       I
        I   I    MZ = MZT/N         I
        I   I                       I
        I   I    AMTOT1 = 0.        I
        I   I                       I
        I   I    AMTOT2 = 0.        I
        I   *-----------------------*
        I                I
        *--------------)I
                 20      I   NOTE  04
            * * * * * * * * * * * * *
            *    BEGIN DO LOOP      *
            *     40 I = 1, N       *
            * * * * * * * * * * * * *
                         I
        *--------------)I
        I                I
        I   CALCULATE WEIGHT LOSS
        I   OF CONSTITUENT ON
        I   EACH SITE/NODE
        I                I
        I                I
        I                I
```

```
I  I      AX1(I) =         I
I  I  X1(I)*MZ*MOLWT       I
I  I                       I
I  I      AX2(I) =         I
I  I  X2(I)*MZ*MOLWT       I
I  *-----------------------*
I             I
I             I
I             I
I  CALCULATE PERCENT
I  LOADING OF
I  CONSTITUENT PER NODE
I             I
I             I
I             I          06
I  *-----------------------*
I  I      LTOT(I) =        I
I  I  (AX1(I)&AX2(I))      I
I  I     *100./MZ          I
I  *-----------------------*
I             I
I             I
I             I
I      40     *    07
I          *     *
I        *         *
I  NO  *             *
*-----*   END OF DO    *
       *    LOOP     *
         *         *
           *     *
              *
              IYES
              I
              I
              I
              I
              I
              I
   CALCULATE AMOUNT OF
   CONSTITUENT THRU BED
   EACH TIME INTERVAL
    LBS.(
              I
              I
              I
              I  /
            -----
           /22.01
```

CHART TITLE - SUBROUTINE FOUT(TIME,DT,N,MOLWT,MZT,DMH,X1,X2,LTOT,PCTL,PCM1,PCM2



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```
          I            I            *              *  (+) I                  I
CALCULATE TOTAL        I          *  MOLWT - 14.   *------+                  *   14
WEIGHT LOST OF         I            *              *                      *     *
CONSTITUENT ON BED     I              *         *                       *         *
          I            I                *     *                       *             *  TRUE
          I            I                   *                       *  DMH(1) .EQ.  *-------------------------)*
          I        05  I                 I(-/0)                      *     0.     *                      65    I        17
*-------------------*  I                   I                          *         *             *-------------------------*
I AMTOT = AMX1&AMX2 I  I                   I                            *     *               I  AMTOT2 = AMTOT         I
*-------------------*  I                   I                               *                  I                         I
          I            I                   I                               IFALSE             I  H2OTOT = 0.            I
          I            I                   I                               I                  *-------------------------*
          I            I          61       I        10                     I                               I
CALCULATE TOTAL        I        *--------------------*                     I        *-------------22.09*--)I
LOADING OF             I        I     H2OTOT *       I                     I        I               70     I   NOTE  13
CONSTITUENT ON BED     I        I   H2OTOT&FCT2      I                     I        I          * * * * * * * * * * *
          I            I        *--------------------*                     I    15  I          *     CONTINUE        *
          I            I                   I                 *---------------------*I          * * * * * * * * * * *
          I        06  I                   I                 I  AMT2D = AMTOT +    II                      I
*-------------------*  I                   I                 I     AMTOT2          II                      I
I     PCTL =        I  I                   *  11             I                     II                      I 19
I  AMTOT*100./MZT   I  I                 *   *               I      EFF =          II                  ---------
*-------------------*  I               *       *             I AMT2D*100./H2OTOT   II                  *  EXIT  *
          I            I            *            *  TRUE     *---------------------*I                  ---------
          I            I         *  DMH(1) .EQ.  *------+              I            I
          I            I            *   0.    *         I              I            I
CALCULATE TOTAL        I               *     *          I              *------------*
LOADING OF             I                  *  *          I                           A
CONSTITUENT ON EACH    I                    *           I                           I
SITE                   I                    IFALSE      I                           I
          I            I                    I           I                           I
          I            I                    I           I                           I
          I        07  I                    I           I                           I
*-------------------*  I                    I           I                           I
I     PCM1 =        I  I                    I           I                           I
I  AMX1*100./MZT    I  I                    I           I                           I
I                   I  I       CALCULATE REMOVAL        I                           I
I     PCM2 =        I  I       EFFICIENCY               I                           I
I  AMX2*100./MZT    I  I                    I           I                           I
I                   I  I                    I           I                           I
I     FCT2 =        I  I                    I      12   I                           I
I  DT*DMH(1)*MOLWT  I  I        *--------------------*  +---------------------)*     I
*-------------------*  I        I AMT1D = AMTOT -    I            65       I     16  I
          I            I        I     AMTOT1         I       *---------------------*   I
          I            I        I                    I       I  AMTOT1 = AMTOT     I   I
          *------------*        I      EFF =         I       I                     I   I
                                I AMT2D*100./H2OTOT  I       I  H2OTOT = 0.        I   I
                                *--------------------*       *---------------------*   I
                                           I                           I             I
                                           I                           I             I
                                           I                           *-------------*
                                          ...
                                         .   .
                                        .22.18.
                                         .   .
                                          ... 70
```

Hamilton Standard

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
REAL  MOLWT, MZ, MZT, LTOT
DIMENSION  X1 100(, X2 100(, LTOT 1(,DMH 100(
DIMENSION AX1 100(, AX2 100(
```

CHART TITLE - SUBROUTINE PVAC(I,DT,N,JIND,C,DH2O,DCO2,PIN,POUT,DMHO,DMCO,PHOUT,

```
           ----------
         /   PVAC    /
          ----------

   05.04---)*

   SET VALUES FOR
   CONSTANTS DURING
   FIRST PASS

              *
              I
              *    01
           *     *
        *           *
     *                *    101
   *       JIND          *------*
     *                *         I
        *           *           I
           *     *              I
              *                 I
              I(-/+)            I
              I                 I
              I                 I
              I                 I
              I                 I
              I                 I
      1       I         02      I
  *-------------------------*   I
  I      VB = C(1)          I   I
  I                         I   I
  I      XMU = C(2)         I   *------------24.01*---)*
  I                         I   A                      I
  I      DIA = C(3)         I   I               5      *    08
  I                         I   I                   *     *
  I   XLEN = C(4)*12.       I   I                *           *
  I                         I   I             *                 *   TRUE
  I       R = 555.          I   I          *     I .GT. 1         *--*
  I                         I   I             *                 *    I
  I      L = XLEN/N         I   I                *           *       I
  *-------------------------*   I                   *     *          I
              I                 I                      *           ....
              I                 I                      IFALSE  .  25  .
              I         C3      I                      I        . C1  .
  *-------------------------*   I                      I           ....
  I  PI = 3.1415927         I   I                      I            10
  I                         I   I                      I
  I        Q =              I   I                      I
  I  A*DIA**2*EPS**3/       I   I                      I            09
  I    (XMU*L*(1. -         I   I          *---------------------------*
  I      EPS)**2)           I   I          I    DELW = Q/TG(I)         I
  I  *60./(1000.*555.(      I   I          I                           I
```

Hamilton Standard

```
I 359*144.*1728.)  I     I FACTH =             I
I                  I     I PIN*(PH2O(1)        I
I VNODE = VB/N     I     I /(PH2O(1)&PCO2(1)   I
*------------------*     I ))                  I   *-----------------)*
        I                I FACTC =             I          7   I      13
        I            04  I PIN*(PCO2(1)        I   *-------------------*
*------------------*     I /(PH2O(1)&PCO2(1)   I   I DMH(1) =          I
I K = (6)          I     I ))                  I   I PH2O(1)/PT(1)*DMI I
*------------------*     *---------------------*   *-------------------*
        I                        I                          I
        I                        I                 *-------------)I
        I NOTE 05                I                    8    I      14
* * * * * * * * * * *    CALCULATE AVERAGE         *-------------------*
* BEGIN DO LOOP     *    TOTAL PRESSURE            I DMC(1) = DMI -    I
* 2 J = 1, K        *            I                 I DMH(1)            I
* * * * * * * * * * *            I                 I PTA =             I
        I                        I          10     I (PT(1)&PT(2))/2.  I
*-------------)I         *---------------------*   *-------------------*
I                        I PTA =               I            I
I CALCULATE TOTAL        I (PIN&PT(1))/2.      I            I
I PRESSURE               I DMI =               I   CALCULATE OUTLET FLOW
I       I                I DELW*PTA*(PIN -     I   THROUGH FIRST NODE
I       I          06    I PT(1))              I            I
I *-------------------*  *---------------------*            I      15
I I PT(J) =           I          I                 *-------------------*
I I PH2O(J)&PCO2(J)   I          I                 I DMO(1) =          I
I *-------------------*          *   11            I DELW*PTA*(PT(1) - I
I         I                    *   *               I PT(2))            I
I         I                  *       *             *-------------------*
I    2    *  07            *           *  (+)              I
I       *   *            *    PT(1)      *------+          I
I     *       *            *           *                   I
I NO *          *            *       *                     *  16
*---* END OF DO  *             *   *                     *   *
     * LOOP     *                *                     *       *  TRUE
       *      *                  I(-/0)              *  N .EQ. 1  *------+
         *  *                    I                     *       *
           *                     I                       *   *
           IYES                  I                         *
           I                     I                         IFALSE
           I                6    I        12               I
           I             *---------------------*           I
           I             I DMH(1) = 0.         I           I
*-------------------*    *---------------------*           I
                                 I                         I
                                 I                         I
                                 *---------------------*   I
                                                          ...
                                                       .25.05.
                                                          ... 20

                 *-----------24,15*--)*
                        25     I       17
                 *-----------------------*
                 I PTA =                 I
                 I (PT(N)&PT(OUT))/2.    I
                 I DELW = D/T(I)         I
                 *-----------------------*
CALCULATE AVERAGE          I
TOTAL PRESSURE FOR         I
LAST NODE                  I
                 CALCULATE OUTLET FLOW
                 OF LAST NODE
                           I
                           I           18
                 *-----------------------*
                 I DMO(N) =              I
                 I DELW*PTA*(PT(N) -     I
                 I POUT)                 I
                 *-----------------------*
                           I
                           *   19
                         *   *
                       *       *   TRUE
                     *  N .EQ. 1  *---.
                       *       *      I
                         *   *        I
                           *         ....
                           IFALSE  . 25 .
                           I       . 05 .
                           I        ....
                           I         20
                           I
                          ...
                        .25.06.
                          ... 15
```

CHART TITLE - SUBROUTINE PVAC(I,DT,N,JIND,C,DH2O,DCO2,PIN,POUT,DMHO,DMCO,PHOUT,

```
/ 10 /

24.08---)
         01
   * I .EQ. N *   TRUE ---> 25.06
   FALSE
   . 24 .
   . 17 .
     25
         02
+--------------------+
I  DELW = Q/TG(I)    I
+--------------------+

CALCULATE AVERAGE
TOTAL PRESSURE AND
OUTLET FLOW FOR NODES
2 THRU
         03
+--------------------+
I   PTA =            I
I (PT(I)&PT(I&1))    I
I   /2.              I
I                    I
I  DMO(I) =          I
I DELW*PTA*(PT(I) -  I
I   PT(I&1))         I
+--------------------+
24.19---)
  16     04
+--------------------+
I DMH(I) = DMHO(I -  I
I   1)               I
I                    I
I DMC(I) = DMCO(I-   I
```

```
------25.06*--)*
                    08
+--------------------+
I   DMHO(I) =        I
I  PH2O(K)/PT(K)     I
I   *DMO(I)          I
I                    I
I   DMCO(I) =        I
I DMO(I) - DMHO(I)   I
+--------------------+

CALCULATE PARTIAL
PRESSURES OF CO2 AND
H2O AND TOTAL
PRESSURE
                    09
+--------------------+
I   DELPC =          I
I  ((DMC(I) -        I
I   DCO2(I) -        I
I DMCO(I))*R*TG(I)   I
I  /VNODE)*DT        I
I                    I
I   DELPH =          I
I  ((DMH(I) -        I
I   DH2O(I) -        I
I DMHO(I))*R*TG(I)   I
I  /VNODE)*DT        I
+--------------------+
         10
FALSE *ABS(DELPC) *
        .GT.
    *.1*PCO2(I) *
        ITRUE
```

```
+------------------)*
        15
(0/+) *  PCO2(I)  *
        I (-)
16                 16
+--------------------+
I PCO2(I) = FACT5    I
+--------------------+
```

```
                         11
CALCULATE H2O AND CO2
OUTLET FLOW RATES -
LB-MOLE/MIN/NODE
24.16*--)I
     20             05
     K = 1
                    06
   DMO(I) .LT. 0.      FALSE
     TRUE
                    07
     K = KEI

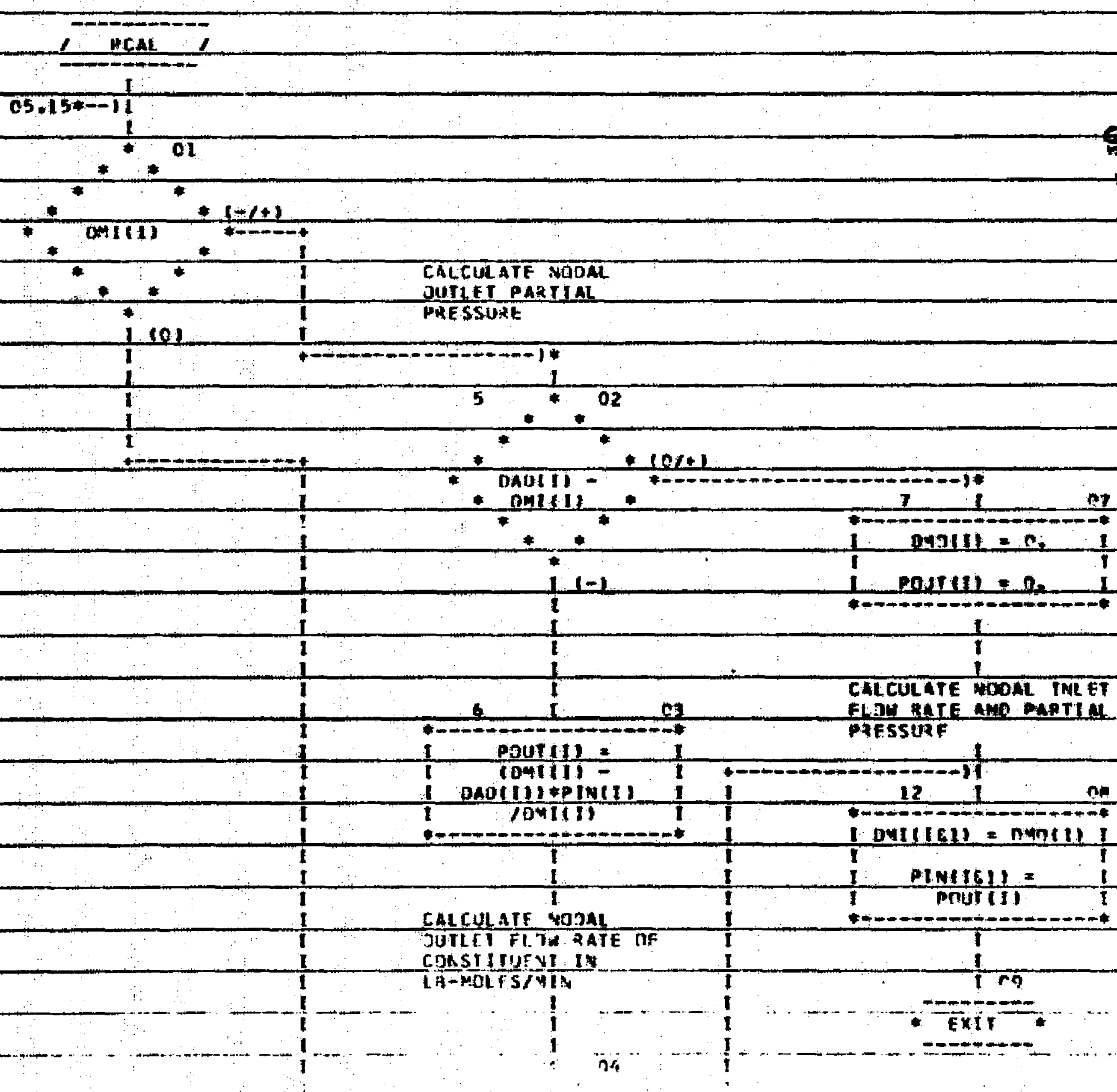
                         11
     DELPC =
     .1*PCO2(I)
     *DELPC/ABS(DELPC)
                         12
FALSE *ABS(DELPH) .GT. .1*PH2O(I)
     TRUE
                         13
     DELPH =
     .1*PH2O(I)
     *DELPH/ABS(DELPH)
                         14
     PCO2(I) =
     PCO2(I)&DELPC
     PH2O(I) =
     PH2O(I)&DELPH

  17                     17
(0/+)    PH2O(I)
         (-)
  18                     18
     PH2O(I) = FACTH
  19                     19
     PT(I) =
     PH2O(I)&PCO2(I)
     PHOUT = PH2O(N)
     PCOUT = PCO2(N)
                         20
     I .EQ. N          TRUE
     FALSE
  23                     21
     PHOUT = PH2O(N)
     PCOUT = PCO2(N)
  33       NOTE          22
     CONTINUE
     23
     EXIT
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
COMMON/OUTPUT/PT, FACTH, FACTC
COMMON/BLOK3/PCO2,PH2O
DIMENSION           DMO 100(,DMH 100(,DMC 100(,DMHO 100(,
          DMCO 100(,PH2O 100(,PCO2 100(,PT 100(, C 4(
, DH2O 1001, DCO2 100(,TS 100(
REAL  L
```

CHART TITLE - SUBROUTINE PCAL(I,DMI,DAD,PIN,POUT,DMO)



```
I                  *        *             I
I            (+) *            *           I
I        +------*   POUT(I)     *         I
I        I       *            *           I
I        I         *        *             I
I        I           *    *               I
I        I              *                 I
I        I              I(-/0)            I
I        I              I                 I
I        I              I                 I
I        I              I                 I
I        I              I                 I
I        I              I                 I
I        I       8      I          05     I
I        I    *---------------------*     I
I        I    I    POUT(I) = 0.     I     I
I        I    *---------------------*     I
I        V              I                 I
+-------------27.01*--->I                 I
                 10     I          06     I
              *---------------------*     I
              I DM3(I) = DM1(I) -   I     I
              I      DAD(I)         I     I
              *---------------------*     I
                        I                 I
                        I                 I
                        +-----------------+
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
DIMENSION  DMI 1(,DAD 1(,PIN 1(,POUT 1(,3MO 1(
```

HS F-927 6/56

TEST NO. ________

HAMILTON STANDARD

PLAN OF TEST

JOB: Desiccant Humidity Control System

PLAN PREPARED BY: P. J. Lunde

PROJECT & ORDER: E61-100-000A

APPROVED BY: ________

INSTRUCTION: Large Scale Improved HS-C Material Demonstration Test

TEST ENGINEER: H. Kolnsberg

TIME PERIOD: January 1972 TO January 1972

1. WHAT IS ITEM BEING TESTED?

2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?

3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.

4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.

5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.

6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1. 5 lbs. HS-C, prepared by Hamilton Standard.

2. To demonstrate improved HS-C material for use on shuttle for desiccant and CO_2 control, in a full scale test.

3. The conditioned air to the canister is run in a closed loop, i.e. air effluent from the canister is reconditioned and becomes incoming air by the addition of water and CO_2. The CO_2 added is weighed and reported for each cycle, but this is not possible with the water because the water is stored within the rig and cannot be easily measured.

Air must be added to the loop once each cycle to compensate for the ullage lost during desorption; this air is weighed and reported.

During the adsorption cycle the control valves will be as shown and air flow directed through the test canister. The CO_2 partial pressure at the canister inlet will be maintained constant by adding CO_2 under closed loop control. The CO_2 cylinder will be weighed after each cycle.

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TEST PLAN

Test Requirements

A. Test Equipment Requirements

Hamilton Standard test rig #88 will be used for this test program (see Figure 1). It will provide a stream of conditioned air to the HS-C material under test with automatically controlled pressure, flow rate, CO_2 partial pressure, dew point, and temperature. The conditioned air shall be maintained for the selected adsorption time while the canister is cooled by a constant temperature water coolant. At the expiration of this time desorption begins automatically with the isolation of the test canister from the conditioned air and the application of a high vacuum to the HS-C in its canister. The water coolant is maintained, and heats the canister during desorption. The entire cycle is repeated until the results repeat, when the system is said to be in "cycle equilibrium."

B. Reliability

The reliability of the test equipment must be such that the initial and final test runs are reproduced within the run tolerance (see item E below).

C. Loads

Not applicable.

D. Predicted Environments

Not applicable.

E. Allowable Tolerances

Each run shall be repeatable to the "run tolerance," defined as $\pm 10\%$ on CO_2 and H_2O capacity.

F. Applicable Standards

None.

LARGE SCALE TESTS
RIG 88 BLOCK DIAGRAM

See Figure 30, Page 39 of text

FIGURE 1

Dew point, pressure, inlet gas temperature, bed temperature and cycle times will be automatically controlled to test values by Rig 88. Desorption vacuum will depend on rig capacity.

The HS-C canister is to be set up on Rig 88 as shown in Figure 1. Rig 88 will be adjusted to give the desired experimental conditions during cyclic operation.

Required measurements are as follows:

	Units	Accuracy
Cycle Time	Minutes	±1% of Interval
Air Flow Rate	in H_2O Reported in CFM	±10% of Flow
Inlet Temperature	°F	±2°F
Inlet Pressure	psia	±0.2 psia
Hygrometer (dew point)	°F	±2°F
Water Temperature	°F	±2°F
Inlet and Outlet CO_2	volts Reported as mm Hg	±2% of full scale (full scale = 5 mm)
Weight CO_2 Added	lbs	±.02 lbs
Weight Air Added	lbs	±.02 lbs
Desorption Vacuum	Microns	±5% of non-linear scale of Hastings gauge, as calibrated for air.

4. HS-C Bed Weight, 5 lbs, Maximum

Nine runs will be made, with test conditions as follows:

Nominal:

Pressure	14.7 psi
P_{CO_2}	5.0 mm Hg
Tgas Inlet	70°F

Continued

Dew Point	52°F
Bed Temperature	80°F
Inlet Flow	20 cfm*
Half-cycle Time	30 minutes*
Desorption Conditions	80°F - Exact desorption pressure will depend on rig considerations since this variable is not under direct control. Target pressure is 20 microns.

*Or as appropriate for the HS-C system design.

Specific Tests:

Run 1	Nominal conditions
Run 2	Increased cycle time
Run 3	Decreased cycle time
Run 4	Decreased dew point (46°F)
Run 5	Increased dew point (57°F)
Run 6	Increased air inlet flow (3/2 nominal; or maximum rig capability)
Run 7	Decreased air inlet flow (2/3 nominal)
Run 8	Decreased P_{CO_2} (3 mm)
Run 9	Nominal conditions

Each run will be continued until a cyclic equilibrium is reached such that the breakthrough curves for water and CO_2 are essentially identical for two successive cycles.

The sequence and numbering of these tests 2-8 may be varied to more efficiently utilize the test equipment and manpower.

During each cycle of record the following variables will be measured at least once or preferably continuously recorded on strip charts.

Inlet Dew Point (recorded as water coolant temperature)
Outlet Dew Point
Inlet P_{CO_2}
Outlet P_{CO_2}
Total Pressure
Inlet Temperature
Bed Coolant Temperature
Inlet Flow
Cycle Times
Desorption Pressure
Air Cylinder Weight
CO_2 Cyclinder Weight

Continued

A cycle of record will be selected by noting that the controlled variables have been constant for two successive cycles, and successive tracings of the recorder charts for outlet P_{CO_2} and dew point show no trends and in general agree ± 1/8-in on the 10-in strip chart. Past experience indicates three cycles are generally sufficient if conditions are held steady.

The cyclic capacity for Run 9 shall be demonstrated at the end of 168 hours of testing as at least 2% for carbon dioxide and 4% for water vapor.

CR-115568
SVHSER-6040

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION

MASTER TEST PLAN

DESICCANT HUMIDITY CONTROL

LARGE SCALE HS-C

OCTOBER 1971

Prepared by: P J Lunde
P. Lunde

Approved by: Wm A. Blecher
W. Blecher

Approved by: Fred H. Greenwood
F. Greenwood
Program Manager

TEST NO. 3

HAMILTON STANDARD

PLAN OF TEST

JOB: Desiccant Humidity Control

PLAN PREPARED BY: P. J. Lunde

PROJECT & ORDER: B77-400-100A

APPROVED BY: W. A. Blecher

INSTRUCTION: Large Scale HS-C

TEST ENGINEER: H. Kolnsberg

TIME PERIOD: October 1971 TO November 1971

1. WHAT IS ITEM BEING TESTED?
2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?
3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.
4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.
5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.
6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1. 5-10 lbs. HS-C prepared in house.

2. To demonstrate feasibility of HS-C material for use on shuttle for desiccant and CO_2 control in a full scale test.

3. The conditioned air to the canister is run in a closed loop, i.e. air effluent from the canister is reconditioned and becomes incoming air by the addition of water and CO_2. The CO_2 added is weighed and reported for each cycle, but this is not possible with the water because the water is stored within the rig and cannot be easily measured.

   Air must be added to the loop once each cycle to compensate for the ullage lost during desorption; this air is weighed and reported.

   During the adsorption cycle the control valves will be as shown and air flow directed through the test canister. The CO_2 partial pressure at the canister inlet will be maintained constant by adding CO_2 under closed loop control. The CO_2 cylinder will be weighed after each cycle.

RIG 88 SET-UP FOR HS-C

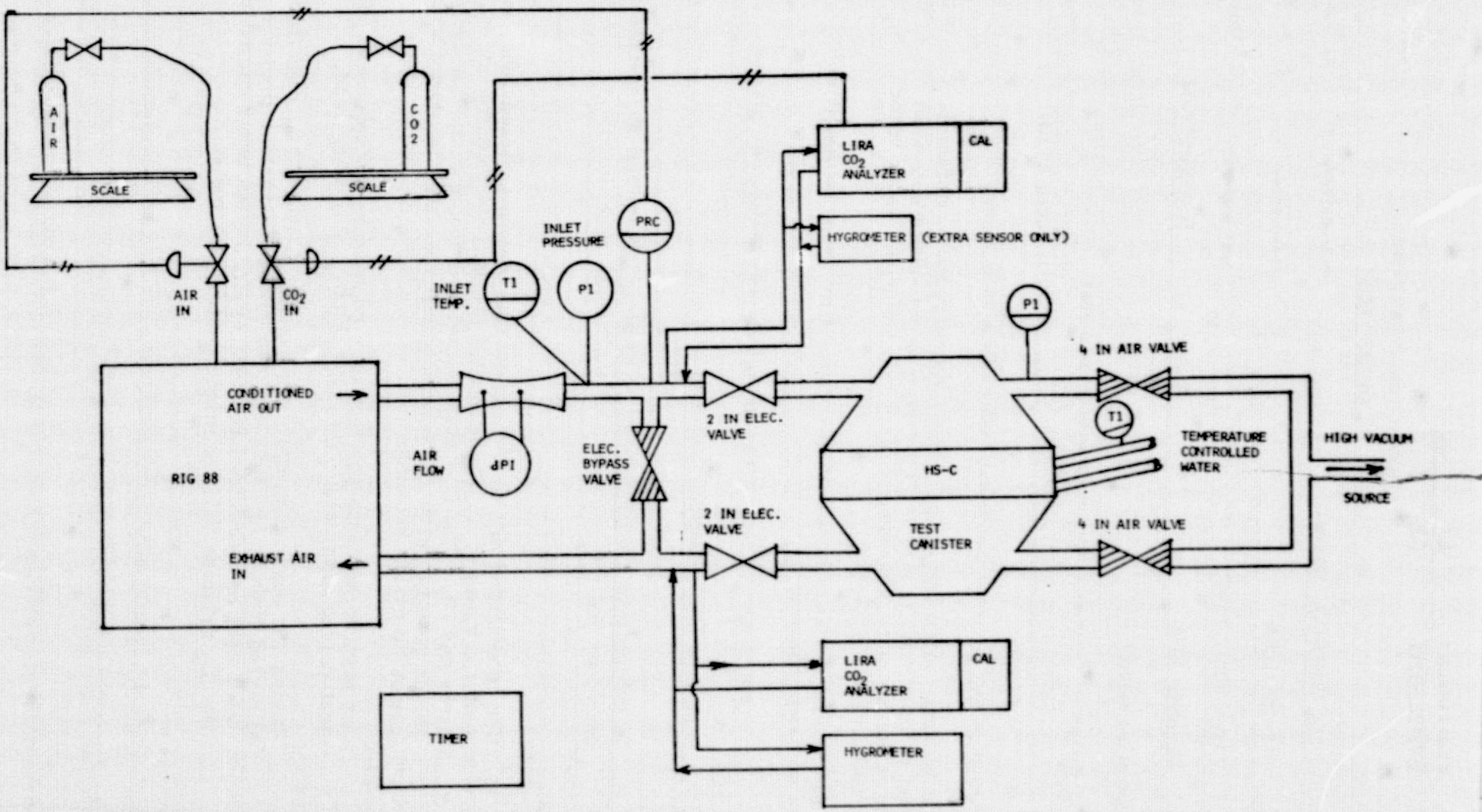

FIGURE 1

MASTER TEST PLAN

Test Requirements

A. Test Equipment Requirements

Hamilton Standard test rig #88 will be used for this test program (see Figure 1). It will provide a stream of conditioned air to the HS-C materila under test with automatically controlled pressure, flow rate, CO_2 partial pressure, dew point, and temperature. The conditioned air shall be maintained for the selected adsorption time while the canister is cooled by a constant temperature water coolant. At the expiration of this time desorption begins automatically with the isolation of the test canister from the conditioned air and the application of a high vacuum to the HS-C in its canister. The water coolant is maintained, and heats the canister during desorption. The entire cycle is repeated until the results repeat, when the system is said to be in "cyclic equilibrium".

B. Reliability

The reliability of the test equipment must be such that the initial and final test runs are reproduced within the run tolerance (see item E below).

C. Loads

Not applicable

D. Predicted Environments

Not applicable

E. Allowable Tolerances

Each run shall be repeatable to the "run tolerance", defined as $\pm$ 10% on CO_2 and H_2O capacity.

F. Applicable Standards

None

Dew point, pressure, inlet gas temperature, bed temperature and cycle times will be automatically controlled to test valves by Rig 88. Desorption vacuum will depend on rig capacity.

The HS-C canister is to be set up on Rig 88 as shown in Figure 1. Rig 88 will be adjusted to give the desired experimental conditions during cyclic operation.

Required measurements are as follows:

	Units	Accuracy
Cycle Time	Minutes	± 1% of Interval
Air Flow Rate	in H_2O Reported in CFM	± 10% of Flow
Inlet Temperature	°F	± 2°F
Inlet Pressure	psia	± 0.2 psia
Hygrometer (dew point)	°F	± 2°F
Water Temperature	°F	± 2°F
Inlet and Outlet CO_2	volts Reported as mm Hg	± 2% of full scale (full scale = 5 mm)
Weight CO_2 Added	lbs	± .02 lbs
Weight Air Added	lbs	± .02 lbs
Desorption Vacuum	Microns	± 5% of non-linear scale of Hastings gauge, as calibrated for air.

4. HS-C Bed Weight, 10 lbs Maximum

Fifteen runs will be made, with test conditions as follows:

Nominal:

Pressure	14.7 psia
P_{CO_2}	3.0 mm Hg
Tgas Inlet	70°F
PO_2	3.1 psia (atmospheric air)
Dew Point	52°F
Bed Temperature	80°F

4. Continued

Inlet Flow	50 cfm*
Half-cycle Time	30 minutes*
Desorption Conditions	80°F - Exact desorption pressure will depend on rig considerations since this variable is not under direct control. Target pressure is 50 microns.

*Or as appropriate for the HS-C system design

Specific Tests:

Run 1	Nominal conditions
Run 2	Increased air inlet temperature (75°F)
Run 3	Decreased air inlet temperature (65°)
Run 4	Decreased dew point (46°F)
Run 5	Increased dew point (57°)
Run 6	Increased bed temperature (90°F)
Run 7	Decreased bed temperature (70°F)
Run 8	Increased P_{CO_2} (5/3 nominal)
Run 9	Decreased P_{CO_2} (1/2 nominal)
Run 10	Increased air inlet flow (3/2 nominal; or maximum rig capability)
Run 11	Decreased air inlet flow (2/3 nominal)
Run 12	Increased cycle time (3/2 nominal)
Run 13	Decreased cycle time (2/3 nominal)
Run 14	Increased desorption pressure. Exact pressure will depend on rig considerations since this variable is not under direct control. Target pressure is 100 microns.
Run 15	Nominal conditions

Each run will be continued until a cyclic equilibrium is reached such that the breakthrough curves for water and CO_2 are essentially identical for two successive cycles.

The sequence and numbering of these tests 2-14 may be varied to more efficiently utilize the test equipment and manpower.

During each cycle of record the following variables will be measured at least once or preferably continuously recorded on strip charts.

- Inlet Dew Point (recorded as water coolant temperature)
- Outlet Dew Point
- Inlet P_{CO_2}
- Outlet P_{CO_2}
- Total Pressure
- Inlet Temperature
- Bed Coolant Temperature
- Inlet Flow
- Cycle Times
- Desorption Pressure
- Air Cylinder Weight
- CO_2 Cylinder Weight

4. Continued

A cycle of record will be selected by noting that the controlled variables have been constant for two successive cycles, and successive tracings of the recorder charts for outlet P_{CO_2} and dew point show no trends and in general agree $\pm$ 1/8-in on the 10-in strip chart. Past experience indicates three cycles are generally sufficient if conditions are held steady.

At the end of Run 1 or 15 the circulating airstream will be sampled and analyzed for the toxicants listed in paragraph 3.4.4 of the SOW.

APPENDIX F

DATA SUMMARY SHEETS

LARGE SCALE TESTS

HSF 1758 4/67

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 1 OF
DATE 11-5-1971
ENGINEER PL, HK, CD
OPERATORS

RIG NO. 88
TYPE OF TEST HS-C SORBENT PARAMETRIC
W.P.I. NO. RUN SERIES I
PLAN OF TEST NO. 9.3 lbs HS-C as bed (wet)
SERIAL NO. 14 6 11 PART NO. 15 1 23 24 9

DATE	TIME BEGIN ADS	SINCE START	CYCLE NO.	WT CO_2 BEGIN ADS	ΔCO_2 END ADS	Δ AIR END ADS	ADS TIME	DES TIME	VACUUM END DES	INLET AIR	INLET CAN COOL	INLET DEW PT	CAN ΔP	ADS PRESS	ADS FLOW	INLET P_{CO_2}	FT LEFT ON ROLL
UNITS →		hrs		lbs	lbs	lbs	MIN	min	μ	°F	°F	°F	in H_2O	psia	CFM	mm Hg	ft
11/5	1335	0	1	155.87	.07	—	22	45	35	74	82	52	2.0	14.6	30	3.4	34
	1445	1.1	2	155.80	.12	—	22	45	30	74	82	52	2.0	14.6	29	3.6	33
	1555	2.2	3	155.68	.11	—	22	45	30	74	103	56	3.2	14.45	40	3.8	32
	1707	3.3	4	155.57	.19	—	22	45	20	75	76	56	3.0	14.5	40	3.5	31
	1820	4.4	5	155.38	.14	—	22	45	30	75	78	54	3.0	14.55	41	3.9	30
	1928	5.5	6	155.24	.14	—	22	45	30	69	78	52	3.0	14.5	40.5	3.8	29
	2126	6.6	7	154.61	.09	—	22	62	35	69	79	49	2.9	14.7	40.5	3.5	27
	2250	8.7	8	154.52	.12	—	22	61	150	69	79	52	2.9	14.65	40.5	3.7	26
11/6	0015	10.1	9	154.40	.13	—	23	62	150	69	79	52	2.9	14.7	40.5	3.9	25
	0142	11.5	10	154.27	.13	—	22	62	39	69	79	52	3.0	14.7	40.5	3.8	23
	0306	12.9	11	154.14	.14	—	22	62	35	69	78	52	2.9	14.7	40.5	3.8	22
	0431	14.3	12	154.00	.14	—	22	63	36	69	78	57	3.0	14.7	40.5	3.8	21
	0557	15.7	13	153.86	.15	—	23	64	37	69	78	52	2.9	14.7	40.5	3.8	20
	0722	17.1	14	153.71	.13	—	22	62	48	69	78	57	2.9	14.7	40.5	3.8	19
	0840	18.5	15	153.58	.14	—	42	60	45	70	78	52	2.9	14.7	40.5	4.1	18
				SHUT	DOWN												

REMARKS:

PAGE NO. REPORT NO.

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CR-115568
SVHSER-6040

HSF 1753 4/67

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONNECTICUT • U.S.A.

UA

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 2 OF

RIG NO. 88

TYPE OF TEST HS-C SORBENT PARAMETER

W.P.I. NO. RUN SERIES I

PLAN OF TEST NO.

SERIAL NO.

PART NO.

DATE

ENGINEER

OPERATORS

AD. DATE	UNITS → TIME BEGIN ADS	HRS SINCE START	CYCLE NO.	lbs WT CO_2 BEGIN ADS	lbs ΔCO_2 END ADS	lbs Δ AIR END ADS	min ADS TIME	min DES TIME	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOL	°F INLET DEW PT	in H_2O CAN ΔP	psia ADS PRESS	CFM ADS FLOW	mmHg INLET P_{CO_2}	ft FT LEFT ON ROLL	
11-8	1240	19.2	16	153.40	.15	—	30	47	12	71	79	54*	3.2	14.05	40.5	3.2	14	
	1350	20.3	17	153.25	.15	—	30	45	15	71	79	56*	4.8	14.8	60	3.3	13	**
	1510	21.7	18	153.10	.16	—	32	45	15	71	79	56*	3.2	~14.75	42	5.1	12	**
11-9	0845	22.5	19	152.94	.245	—	35	1020	6@128°F	70	79	54*	3.4	14.7	42.5	5.0	8	**
	1008	23.8	20	152.69	.17	—	34	47	18	70	79	55*	3.4	14.8	42	5.0	7	**
	1127	25.2	21	154.15	.16	—	33	45	18	70	80	57*	4.	14.9	43	5.1	5	**
	1235	26.4	22	153.95	.15	.15	33	35	25	70	80	55*	~4	~14.9	~43	~5	4	**
	1405	27.8	23	153.80	.15	.15	30	60	140+	70	80	54*	3.2	14.7	41.2	4.85	3	
	1510	29.0	24	153.65	.15	.28	31	35	20	70	81	45‡	3.4	14.7	42	4.9	2	**
	1627	30.3	25	153.50	.15	—	30	45	30	70	80	44	3.0	14.7	41.3	4.8	1	
11-10	0912	40.0	26	153.35 153.25	.225	.16	32	960	4	70	82	52	3.2	14.7	41.5	5.0	98	
	1030	41.3	27	153.13	.15	.16	32	45	15	70	82	52	3.1	14.65	41.2	3.1	97	
	1135	42.4	28	152.99	.13	.20	31	32	25	70	82	52	3.2	14.8	41.5	3.0	96	
	1252	43.6	29	152.86	.14	—	32	45	15	71	82	52	3.3	14.75	41.5	3.05	96	
	1415	44.9	30	152.72	.15	(2 cycles) .31	33	45	15	71	82	52	3.2	14.75	41.5	3.0	95	

REMARKS: * D.P. probably out of cal. Water temp indicates 52°F D.P., or may be a recorder problem **

** Recorder insane on mv range

+ single (other) end desorb ‡ water 42°F

PAGE NO.

REPORT NO.

F-4

CR-115568
SVHSER-6040

HSF 1791 4/67

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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 3 OF 11

DATE
ENGINEER
OPERATORS

RIG NO. 88
TYPE OF TEST AS-C SORBENT PARAMETER
PLAN OF TEST NO.
W.P.I. NO. RUN SERIES I
SERIAL NO.
PART NO.

DATE	UNITS → TIME BEGIN ADS	HRS SINCE START	CYCLE NO.	lbs WT CO_2 BEGIN ADS	lbs ΔCO_2 END ADS.	lbs Δ AIR END ADS	min ADS TIME	min DES TIME	μ VACUUM END DES.	°F INLET AIR	°F INLET CAN COOLANT	°F INLET DEW PT	in H_2O CAN ΔP	psia ADS PRESS	CFM ADS FLOW	mmHg P_{CO_2}	ft FT LEFT ON ROLL
11-10	1534	46.2	31	152.47	.15	.18	31	45	15	71	82	53	3.0	14.7	41	3.0	92
	1655	47.4	32	152.32	.14	.19	30	45	15	71	82	51	3.0	14.7	41.2	3.05	91
	1815	48.6	33	152.18	.14	—	30	45	20	71	82	51	2.9	14.7	41.2	3.05	90
	2000	50.	34	152.04	.15	for two .36	33	45	15	70	80	50	2.7	14.7	40.7	3.0	89
	2120	51.3	35	151.89	.15	.19	30	45	15	71	77	50	2.7	14.7	40.7	3.0	88
	2237	51.5	36	151.74	.14	.18	30	47	15	70	79	44	2.7	14.7	40.7	3.0	86
	2353	52.7	37	151.60	.14	.18	30	45	15	70	80	44	2.7	14.7	40.7	3.0	85
11-11	0110	54.0	38	151.46	.13	.18	30	45	15	70	80	44	2.7	14.7	40.7	3.0	84
	0228	55.2	39	151.33	.15	.18	30	45	15	70	81	57	2.7	14.7	40.7	3.0	83
	0346	56.5	40	151.18	.14	.18	30	45	15	70	80	57	2.8	14.7	40.7	3.0	82
	0502	57.7	41	151.04	.14	.17	30	45	15	70	80	57	2.8	14.7	40.7	3.0	81
	0621	59.0	42	150.89	.14	.18	30	45	15	70	80	51	2.8	14.7	40.7	3.0	80
	0738	60.2	43	150.75	.14	.18	30	45	15	70	80	52	2.8	14.7	40.7	3.0	79
	0855	61.4	44	150.61	.14	.17	30	45	15	70	81	51	2.8	14.7	40.7	3.0	78
	1013	62.6	45	150.47	.14	.17	30	45	15	75	80	51	2.8	14.7	40.7	3.0	77

REMARKS:

PAGE NO.

REPORT NO.

CR-115568
SVHSER-6040

F-6

HSF 17/3 4/67

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WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 4 OF

RIG NO. 88
TYPE OF TEST HS-C SORBENT PARAMETER
W.P.I. NO. RUN SERIES I
PLAN OF TEST NO.
SERIAL NO. 6 11 PART NO. 13 1 23 24 9
DATE
ENGINEER
OPERATORS

A.D. DATE	UNITS → TIME BEGIN ADS	HRS SINCE START	CYCLE NO.	lbs WT CO_2 BEGIN ADS	lbs ΔCO_2 END ADS	lbs Δ AIR END ADS	min ADS TIME	min DES TIME	μ VACUUM END DES.	°F INLET AIR	°F INLET CAN COOLANT	°F INLET DEW PT	in H_2O CAN ΔP	psia ADS PRESS	CFM ADS FLOW	mmHg P_{CO_2}	ft FT LEFT ON ROLL
11-11	1134	63.9	46	150.33	.14	.16	30	45	13	75	82	52	2.7	14.7	40.5	3.0	75
	1247	65.2	47	150.19	.14	.16			13	76	82	52	2.7	14.7	40.5	3.0	74
	1406	66.5	48	150.05	.10	.15			13	76	83	52	2.7	14.7	40.5	3.0	73
	1524	67.8	49	149.95	.14	.15			13	61	83	52	2.7	14.7	40.5	3.0	72
	1641	69.1	50	149.81	.14	.14			13	60	83	52	2.7	14.7	40.5	3.0	71
	1759	70.4	51	149.67	.14	.16			15	65	83	52	2.7	14.7	40.5	3.0	70
	1916	71.7	52	149.53	.14	.18			15	65	83	52	2.7	14.7	40.5	3.0	69
	2032	73.0	53	149.39	.14	.21			15	68	84	52	2.7	14.7	40.5	3.0	68
	2151	74.3	54	149.25	.15	.27			15	70	80	52	2.7	14.7	40.5	3.0	67
	2310	75.6	55	149.10	.14	.18			15	70	81	51	2.7	14.7	40.5	3.0	66
HI CAN OFF 11-12	0028	76.9	56	148.96	.145	.18			12	70	92	50	2.7	14.7	40.5	3.0	65
	0144	78.2	57	148.825	.145	.14			15	70	90	50	2.7	14.7	40.5	3.0	64
	0303	79.5	58	148.68	.14	.16			16	70	92	50	2.7	14.7	40.5	3.0	63
LO CAN 70°F	0420	80.8	59	148.54	.17	.17			12	70	67	50	2.7	14.7	40.5	3.0	62
	0538	81.1	60	148.37	.13	.20			22	70	67	50	2.7	14.7	40.5	3.0	60

REMARKS:

PAGE NO.

REPORT NO.

CR-115568
SVHSER-6040

HSF 1753 4/67

Hamilton Standard

DIVISION OF UNITED AIRCRAFT CORPORATION

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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 5 OF [illegible]

RIG NO. 88

TYPE OF TEST HS-C SORBENT PARAMETER

W.P.I. NO. RUN SERIES I

PLAN OF TEST NO.

SERIAL NO. 6 11 PART NO. 13 1 23 24 9

DATE

ENGINEER

OPERATORS

DATE	TIME BEGIN ADS	SINCE START	CYCLE NO.	WT CO_2 BEGIN ADS	ΔCO_2 END ADS	Δ AIR END ADS	ADS TIME	DES TIME	VACUUM END DES	INLET AIR	INLET CAN COOL	INLET DEW PT	CAN ΔP	ADS PRESS	ADS FLOW	P_{CO_2}	ft left on roll	
UNITS →		HRS		lbs	lbs	lbs	min	min	μ	°F	°F	°F	in H_2O	psia	CFM	mm Hg	ft	
11/12	0812	93.7	62	148.105	.135	.18	30	45	20	70	68	49	2.7	14.7	40.5	3.0	58	LO CAN
	0928	94.9	63	147.97	.13	.18	30	45	17	70	68	50	2.7	14.7	40.5	3.0	57	"
	1217	96.85	64	147.84	.14	.19	30	82.5	9	70	80	49	2.7	14.7	40.5	3.0	55	3/4 [illegible]
	1408	98.7	65	147.70	.16	.19	30	82.5	9	70	81	50	2.7	14.7	40.5	3.0	53	"
	1606	100.6	66	147.54	.16	.19	30	82.5	20	70	81	50	2.7	14.7	40.5	3.0	51	"
	1708	101.6	67	147.38	.12	.15	20	30	28	71	81	50	2.7	14.7	40.5	3.0	51	2/3 [illegible]
	1800	102.5	68	147.26	.12	.15	20	30	15	71	81	50	2.7	14.7	40.5	3.0	50	"
	1851	103.5	69	147.14	.12	.15	20	30	20	71	82	50	2.7	14.7	40.5	3.0	49	"
	1956	104.5	70	147.02	.14	.15	30	45	22	70	82	50	2.7	14.7	40.5	3.0	48	NOM
	2116	105.8	71	146.88	.14	.15	30	45	23	71	82	49	2.7	14.7	40.5	4.95	47	
	2231	107.0	72	146.74	.16	.18	30	45	18	71	82	48	2.7	14.7	40.5	5.0	46	
11/13	2346	108.3	73	146.58	.15	.17	30	45	17	71	82	47	2.7	14.7	40.5	4.8	45	P_{CO_2}=5
	0105	109.6	74	146.43	.15	.19	30	45	20	70	82	46	2.7	14.7	40.5	4.8	44	"
	0222	110.8	75	146.28	.15	18	30	45	20	71	82	45	2.7	14.7	40.5	4.8	43	"
	0339	113.0	76	146.13	.10	.19	30	45	20	70	82	44	2.7	14.7	40.5	1.6	42	
	0455	114.2	77	146.03	.10	.19	30	45	17	70	82	43	2.7	14.7	40.5	1.6	41	P_{CO_2}=1.5

REMARKS:

PAGE NO.

REPORT NO.

CR-115568
SVHSER-6040

F-8

HSF 1735 4/67 **Hamilton Standard** DIVISION OF UNITED AIRCRAFT CORPORATION U A.
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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 6 OF

DATE 11-13-71
ENGINEER HK, PL, CD
OPERATORS M, OT, OL, A

BLDG NO. 88
TYPE OF TEST HS-C SORBENT PARAMETRIC
LOCATION OF TEST NO.
W.P.I. NO. RUN SERIES I
SERIAL NO.
PART NO.

DATE 11/71	UNITS → TIME BEGIN ADSORB	HRS TOTAL SINCE START	— CYCLE NO. ○	LBS WT CO_2 BEGIN ADS.	LBS Δ_{CO_2} END ADS.	LBS Δ_{AIR} END ADS	MIN ADS TIME	MIN DES TIME	μ VACUUM END DES 14+	°F INLET AIR T 6	°F INLET CAN COOL 11	°F INLET DEW PT 13+	in H_2O CAN PRESS DROP 1+	PSIA ADSORB PRESS 23+	CFM ADSORB FLOW 24+	mmHg ~~REMA~~RKS INLET P_{CO_2} 9+	FEET ON ROLL
11-13			76														
			77														
	0611	115.5	78	145.93	.10	.19	30	45	18	70	82	43	2.7	14.7	40.5	1.35	40
	0729	116.7	79	145.82	.13	.19	30	45	16	70	82	43	2.7	14.7	40.5	2.8	38
NOM	0842	118.0	80	145.69	.145	.17	30	45	11	70	82	51	5.6	14.8	60	2.9	38
HI ADW	1005	119.2	81	145.545	.150	.16	30	45	15	70	80	50	5.4	14.75	60	3.3	37
	1123	120.5	82	145.395	.145	.17	30	45	19	70	80	51	5.5	14.7	60	3.3	36
	1237	121.8	83	145.25	.14	.18	30	45	18	71	80	51	5.6	14.7	60	3.3	35
LO FLO	1356	123.1	84	145.11	.135	.23	30	45	19	69-72*	78-82*	45*	1.3	14.7	26	3.3	34
	1513	124.4	85	144.975	.135	.21	30	45	19	71	80	51	1.4	14.65	26	3.2	33
	1627	125.6	86	144.84	.135	.19	30	45	17	71	80	52	1.4	14.68	26.2	3.2	31
	1744	126.9	87	144.715	.135	.19	30	45	20	71	80	51	1.4	14.65	26	3.1	30
HI P_{CO_2}	1902	128.2	88	144.58	.160	.10	30	45	18	71	80	51	2.7	14.7	40.5	4.9	29
	2018	129.5	89	144.42	.160	.160	30	45	18	71	80	51	2.7	14.7	40.5	4.9	28
	2135	130.8	90	144.26	.150	.170	30	45	20	72	82	51	2.7	14.7	40.5	4.9	27

REMARKS: * Ran out of water, recorder insane

PAGE NO.

REPORT NO.

CR-115568
SVHSER-6640

HSF 1758 4/67

Hamilton Standard

DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 7 OF
DATE 11-13-71
ENGINEER PL, HK, CD
OPERATORS

RIG NO. 88
TYPE OF TEST HS-C SORBENT PARAMETRIC
W.P.I. NO. RUN SERIES I
PLAN OF TEST NO.
SERIAL NO.
PART NO.

DATE 1971	UNITS ➝ TIME	HRS TOTAL SINCE	— CYCLE NO	LBS WT CO_2	LBS ΔCO_2	LBS Δ AIR	MIN ADS TIME	MIN DES TIME	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOL	°F INLET DP	IN. H_2O CAN ΔP	PSIA ADSORB PRESS	CFM ADSORB FLOW	MM Hg INLET PCO_2	FT LEFT ON
	BEGIN ADSORB	START		BEGIN ADS.	END ADS	END ADS			14	6	11	13	1	23	24	9	ROLL
11/13	2251	132.05	91	144.11	.15	.17	30	45	18	72	82	51	2.7	14.7	40.5	4.9	26
11/14	0009	133.35	92	143.96	.11	.17	30	45	17	71	80	51	2.7	14.7	40.5	1.8	25
LO P_{CO_2}	0125	134.6	93	143.85	.11	.18	30	45	17	71	80	51	2.7	14.7	40.5	1.4	24
	0241	135.9	94	143.74	.11	.18	30	45	15	71	80	51	2.7	14.7	40.5	1.5	23
	0357	137.2	95	143.63	.11	.18	30	45	15	71	80	51	2.7	14.7	40.5	1.5	22
	0514	138.4	96	143.52	.11	.18	30	45	15	71	80	51	2.7	14.7	40.5	1.5	21
NOM	0630	139.7	97	143.40	.14	.18	30	45	15	70	80	51	2.7	14.7	40.5	1.5/3.0	20
	0746	141.0	98	143.26	.14	.18	30	45	15	71	80	52	2.8	14.7	40.5	3.0	18
HI VAC	0903	142.3	99	143.12	.09	.18	30	45	1000*	71	80	52	2.75	14.7	40.5	3.0	17
I	1019	143.5	100	143.03	.09	.18	30	45	1000*	71	80	52	2.75	14.7	40.5	3.0	16
HI VAC	1136	144.8	101	142.94	.12	.18	30	45	160*	71	80	52	2.75	14.7	40.5	3.0	15
II	1252	146.0	102	142.82	.12	.18	30	45	165*	71	80	52	2.75	14.7	40.5	3.0	14
	1408	147.2	103	142.70	.12	.18	30	45	160*	71	80	51	2.75	14.7	40.5	3.0	13
NOM	1526	148.5	104	142.58	.14	.18	30	45	20	71	80	51	2.70	14.7	40.5	3.0	12
	1642	149.7	105	142.44	.14	.18	30	45	25	71	80	51	2.70	14.7	40.5	3.0	11

REMARKS: *Single end desorb. 1000μ measured low pressure side. 160μ high pressure side

thru ullage tube alone

thru bottom valve alone

PAGE NO.

REPORT NO.

CR-115568
SVHSER-6040

F-10

HSF 1758 4/67

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 8 OF ___
DATE 11-14-71
ENGINEER PL, HK, CD
OPERATORS

RIG NO. 88
TYPE OF TEST HS-C SORBENT PARAMETRIC
W.P.I. NO. RUN SERIES I
PLAN OF TEST NO. 8.84 lbs HS-C
SERIAL NO. 14 6 11 PART NO. 13 1 23 24 9

	UNITS →	HRS		lbs	lbs	lbs	min	min	μ	°F	°F	°F	in H_2O	psia	CFM	mm Hg	ft
DATE	TIME BEGIN ADS	SINCE START	CYCLE NO.	WT CO_2 BEGIN ADS	ΔCO_2 END ADS	Δ AIR END ADS	ADS TIME	DES TIME	VACUUM END DES	INLET AIR	INLET CAN COOL	INLET DEW PT	CAN ΔP	ADS PRESS.	ADS FLOW	INLET P_{CO_2}	FT LEFT ON ROLL
11-14	1800	150.9	106	142.30	.14	.19	30	45	25	70	80	51	2.7	14.7	40.5	3.0	10
NOM	1915	152.1	107	142.16	.14	.19	30	45	20	70	80	50*	2.7	14.7	40.5	3.0	9
↓	2031	153.7	108	142.02	.14	.19	30	45	21	70	80	50*	2.8	14.7	40.3	3.0	8
1½ HR DES	0006	157.3	109	~~141.88~~ 141.87	.195	.18	30	181.3	7	70	79	51	2.6	14.7	40.2	5.0	5
2 HR DES	0231	159.7	110	141.675	.185	.18	30	113	10	70	79	52	2.7	14.7	40.6	5.0	3
	0503	162.1	111	141.49	.185	.14**	30	120	9	70	79	51	2.7	14.7	40.6	5.05	1
	0734	164.3	112	141.305	.20	.16	30	120	6	72	80	51	2.7	14.7	40.5	5.0	29
	1006	166.8	113	141.105	.18	.18	30	120	10 ⊛	68 †	— †	51	2.7	14.7	40.5	5.0	27
	1321	170.05	114	140.925	.185	.18	30	165	7	— †	— †	51	2.7	14.7	40.5	5.0	24
	1553	172.3	115	140.74	.20	.18	30	120	8	— †	— †	52	2.7	14.7	40.6	5.0	22
90 min DES	1754	174.6	116	140.54	.18	.18	30	90	8	— †	— †	52	2.7	14.7	40.6	5.0	20
"	1957	176.6	117	140.36	.18	.16	30	90	8	— †	— †	52	2.7	14.7	40.5	5.0	19
45 min DES	2112	177.8	118	140.18	.16	.17	30	45	25	— †	— †	52	2.7	14.7	40.5	5.0	17.5
NOM + low DP	2228	179.0	119	140.02	.11	.18	30	45	25	†	†	42	2.7	14.65	40.5	3.0	16
"	2344	180.2	120	139.91	.13	.18	30	45	23	†	†	42	2.7	14.7	40.5	3.0	15.5

REMARKS: * Ref charge low † TC readings off on recorder - thermometer indicates 68°F at CAN INLET
** Wts changed
⊛ vacuum ~5 @ 0930

PAGE NO. REPORT NO.

CR-115568
SVHSER-6040

HSF 1758 4/67

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 9 OF 11

DATE 11-16-71

RIG NO. 88

ENGINEER PL, HK, CD

TYPE OF TEST HS-C SORBENT PARAMETRIC

PLAN OF TEST NO. 8.84 lbs HS-C

OPERATORS

W.P.I. NO. RUN SERIES I

SERIAL NO. 14 6 11 PART NO. 13 1 23 24 9

DATE	TIME BEGIN ADS	SINCE START	CYCLE NO.	WT CO_2 BEGIN ADS	ΔCO_2 END ADS	Δ AIR END ADS	ADS TIME	DES TIME	VACUUM END DES	INLET AIR	INLET CAN COOL	INLET DEW PT	CAN ΔP	ADS PRESS	ADS FLOW	INLET P_{CO_2}	FT LEFT ON COLL
UNITS →		HRS		lbs	lbs	lbs	min	min	μ	°F	°F	°F	in H_2O	psia	CFM	mm Hg	ft
11/16 NOM + LOW DP	0102	181.4	121	139.78	.13	.18	30	45	23	+	+	42	2.7	14.7	40.5	3.0	14
LOW FLOW LOW DP	0219	182.6	122	139.65	.13	.18	30	45	25	+	+	42	1.4	14.7	26.0	3.0	13
"	0335	183.8	123	139.52	.12	.13	30	45	25	+	+	42	1.4	14.7	26.0	3.0	12
"	0451	185.0	124	139.40	.12	.17	30	45	25	+	+	42	1.4	14.7	26.0	3.0	11
HI FLOW LOW DP	0608	186.2	125	139.28	.13	.18	30	45	25	+	+	47-40	4.5	14.7	55.0	3.0	10
"	0726	186.5	126	139.15	.13	.21	30	45	13	+	+	47-40	4.5	14.7	55.0	3.0	9
	0859*	187.8	127	139.02	.14	.27	30	45	12	+	+	38	4.6	14.7	55.0	3.0	8
	1015	189.1	128	138.88	.13	.18	30	45	10	+	+	43	4.4	14.7	55.0	3.0	7
	1133	190.4	129	138.75	.14	.17	30	45	20	+	+	42	4.7	14.7	55.0	3.0	6
	1249	191.7	130	138.61	.135	.18	30	45	25	+	+	43	4.6	14.7	55.0	3.0	5
	1407	193.0	131	138.47	.135	.11	30	45	22	+	+	42.5	4.8	14.7	55.0	3.0	3
	1507	194.0	132	138.340 / 138.35	.125	.18	30	30	22	+	+	40.0	2.7	14.7	40.5	5.0	3
	1609	195.0	133	138.21	.135	.19	30	30	21	68	77	42	2.7	14.7	40.6	5.0	2
	1715	196.1	134	138.075	.13	.12	30	30	22	70	76	42	2.7	14.7	40.6	5.0	97
	1816	197.1	135	137.95	.135	.18	30	30	22	70	77	42	2.7	14.7	40.6	5.0	96

REMARKS: + TC readings off on recorder - thermometer indicates 68°F at can inlet, can 77°F on Press gauge.
* 18 MIN HOLD WHILE LIRA CAL
@ 100% on recorder flow is 55 CFM ΔP = 38 in H_2O

PAGE NO. REPORT NO.

CR-115568
SVHSER-6040

F-12

HSF 1738 4/67

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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 10 OF

DATE 11-16-71

ENGINEER PL, HK, CD

OPERATORS

RIG NO. 88

TYPE OF TEST HS-C SORBENT PARAMETRIC

PLAN OF TEST NO. 8.84 lbs HS-C

W.P.I. NO. RUN SERIES I

SERIAL NO. 14 6 11 PART NO. 13 1 23 24 9

DATE	TIME BEGIN ADS	HRS SINCE START	CYCLE NO.	WT CO_2 BEGIN ADS	Δ CO_2 END ADS	Δ AIR END ADS	ADS TIME	DES TIME	VACUUM END DES	INLET AIR	INLET CAN COOL	INLET DEW PT	CAN ΔP	ADS PRESS	ADS FLOW	INLET P_{CO_2}	FT LEFT ON ROLL
UNITS ►		HRS		lbs	lbs	lbs	min	min	μ	°F	°F	°F	in H_2O	psia	CFM	mm Hg	ft
11/16	1918	198.1	136	137.815	.135	.18	30	30	22	70	78	52	2.7	14.7	40.5	5.0	95
	2020	199.1	137	137.68	.135	.18	30	30	25	70	78	52	2.7	14.7	40.5	5.0	94
	2122	200.1	138	137.545	.145	.18	30	30	26	70	78	52	2.7	14.7	40.5	5.0	93
	2224	201.1	139	137.40	.145	.18	30	30	26	70	78	62	2.7	14.7	40.5	5.0	92
	2325	202.1	140	137.255	.145	.18	30	30	32	70	78	61	2.7	14.7	40.5	5.0	91.5
11/17	0026	203.1	141	137.11	.15	.17	30	30	33	70	77	58	4.6	14.7	56	5.0	91
	0128	204.1	142	136.96	.15	.17	30	30	25	70	77	51	4.6	14.7	56	5.0	90
	0229	205.2	143	136.81	.14	.23	30	30	28	70	77	42	4.6	14.7	56	5.0	89
	0502	207.7	144	136.67	.18	.19	30	120	10	71	78	51	2.7	14.7	40.2	5.0	87
	0734	210.2	145	136.49	.18	.19	30	120	9	72	78	51	2.7	14.7	40.2	5.0	85
	1004	212.7	146	136.31	.19	.18	30	120	10	70	77	51	2.7	14.7	40.2	4.9	83
	1236	215.3	147	136.12	.19	.17	30	120	7	70	77	51	2.6	14.7	40.2	5.0	81
	1345	216.4	148	135.93	.115*	.17	30	45	20	70	80	51	2.6	14.7	40.5	3.0	80
	1502	217.7	149	135.815	.135	.19	30	45	20	70	81	51	2.8	14.7	41.2	3.0	79
	1618	219	150	135.68	.145	.19	30	45	30	70	81	51	2.8	14.7	41.3	3.0	78

REMARKS: *Changed weights

PAGE NO.

REPORT NO.

CR-115568
SVHSER-6040

HSF 1758 4/67

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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 11 OF 11

DATE 12-2-71

ENGINEER W. BLECHER

OPERATORS W. KOLNSBERG

RIG NO. 88

TYPE OF TEST HSC SORBENT - HALF BED

PLAN OF TEST NO. 4.40# HS-C

W.P.I. NO. RUN SERIES II

SERIAL NO.

PART NO.

DATE	UNITS ► TIME BEG ADS	HRS SINCE START	CYCLE NO.	LBS WT CO_2 BEG ADS	LBS Δ CO_2 END ADS	LBS Δ AIR END ADS	MIN ADS TIME	MIN DES TIME	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOL	°F INLET DEW PT	IN. H_2O CAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	MM Hg INLET PCO_2	FT LEFT ON ROLL
12/2	1045	2.4	1	134.45	.085	.19	38	38	14	70	80	51		14.5	20	4.8	54
	1203	3.7	2	134.365	.085	.18	39	41	13	72	80	53		14.53	20	4.8	53
	1320	5.0	3	134.28	.085	.18	39.5	39	13	72	81	53		14.55	20	4.9	52
	1450	6.5	4	134.195	.085	.18	49.5	49.6	9.5	72	80	52		14.53	20	5.0	50
	1630	8.1	5	134.11	.085	.18	45.5	50.5	9.5	72	80	53	0.4	14.45	20	5.0	48
	1746	9.4	6	134.025	.085	.18	30.74	31.0	17	72	80	53	0.4	14.45	20	5.0	47
	1847	10.4	7	133.94	.08	.19	30.36	29.7	18	72	81	53	0.4	14.45	20	5.0	47
	1950	11.5	8	133.86	.07	.18	30.4	29.22	14	72	81	52	0.4	14.44	20	4.9	46
	2101	12.7	9	133.79	.075	.18	40.0	39.94	12	72	81	51	0.4	14.44	20	4.9	45
	2224	14.0	10	133.715	.075	.13	40.0	39.95	14	72	80	56	1.75	14.46	40	4.9	44
12/3	0927	15.4	11	133.64	—*	.15	30.1	45.02	14	72	83	59	1.75	14.5	40	4.9	42
	1044	16.7	12	133.44	.085	.20	30.1	44.92	12	70	82	50	1.75	14.45	40	4.9	40
	1200	18.0	13	133.355	.090	.18	30.0	45.07	9	70	82	51	0.4	14.43	20	4.9	39
	1317	19.3	14	133.265	.085	.18	30.0	45.07	9	70	82	51	0.4	14.43	20	4.9	38
	1428	20.4	15	133.18	.08	.18	39.5	39.37	10	70	82	51	0.4	14.43	20	4.9	37
	1550	21.8	16	133.11†	.08	.18	41.08	39.85	12	70	82	50	0.4	14.43	20	4.9	36

REMARKS: * CO_2 BOTTLE DISTURBED DURING ADSORB- SCALE READING CHANGED

† SCALE WEIGHTS CHANGED - Δ CO_2 VALID

PAGE NO.

REPORT NO.

CR-115568
SVHSER-6040

HSF 1758 4/67

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP.
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CR-115568
SVHSER-6040

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 1 OF 2
DATE 3-13-72
ENGINEER PJ, DRC
OPERATORS

RIG NO. 81
TYPE OF TEST WATER & CO_2 CAPACITY
W.P.I. NO. CALCULATIONS
PLAN OF TEST NO.
SERIAL NO.
PART NO.

F-14

UNITS → TIME	SERIES	CYCLE NO.	LBS BED WT	LBS CO_2 REMOVED	% CO_2 CAPY.	% H_2O REM. EFF.	LBS H_2O REMOVED	% H_2O CAPY.	CFM AIR FLOW	CFM/LB BED SPECIFIC FLOW RATE
	I	19	8.83	0.245	2.77					
	I	21	8.83	0.16	1.82					
	I	26	8.83	0.225	2.55	40.9	.338	3.83		
	I	41	8.83	0.14	1.58	42.6	.392	4.44	40.7	
	I	43	8.83	0.14	1.58	SAME AS 47 or 52				
	I	47	8.83	0.14	1.58	42.8	.324	3.67	40.5	
	I	52	8.83	0.14	1.58	42.6	.324	3.67	40.7	
	I	5[illegible]	8.83	0.145	1.64					
	I	63	8.83	0.13	1.46	55.0	.381	4.3	40.5	
	I	66	8.83	0.16	1.81					
	I	68	8.83	0.12	1.36					
	I	70	8.83	0.14	1.58	[illegible]	.354	4.00	40.3	4.55
	I	82	8.83	0.145	1.64	38.3	.418	4.72	60	6.78
	I	87	8.83	0.135	1.52	55.5	.26	2.94	26	2.94
	I	91	8.83	0.15	1.70	43.5	.318	3.6	40.5	
	I	96	8.83	0.11	1.24	43.4	.317	3.59	40.5	

REMARKS:

CR-115568
SVHSER-6040

PAGE NO.

REPORT NO.

HSF 1758 4/67

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPOR.

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CR-115568
SVHSER-6040

LOG OF TEST
ENGINEERING LABORATORIES

DATE 3-15-72
ENGINEER PD DRM
OPERATORS

RIG NO.
TYPE OF TEST WATER & CO_2 CAPACITY CALCULATIONS
PLAN OF TEST NO.
W.P.I. NO.
SERIAL NO.
PART NO.

TIME	SERIES	CYCLE NO.	LBS BED WT.	LBS CO_2 REMOVED	% CO_2 CAPY.		% H_2O REM EFF.	LBS H_2O REMOVED	% H_2O CAPY		CFM AIR FLOW	CFM/LB BED SPECIFIC FLOW RATE
	I	100	8.83	0.09	1.02							
	I	101	8.83	0.12	1.36							
	I	109	8.83	0.195	2.21		42.5	.310	3.51		40.6	
	I	113	8.83	0.18	2.03							
	I	115	8.83	0.20	2.26							
	I	121	8.83	0.13	1.47		43.4	.225	2.55		40.5	4.58
	I	124	8.83	0.12	1.36		52.5	.172	1.95		26	2.94
	I	131	8.83	0.135	1.53		35.2	.248	2.80		55	6.21
	I	137	8.83	0.135	1.53		44.4	.353	4.0		40.5	4.58
	I	138	8.83	0.145	1.64							
	I	147	8.83	0.19	2.15							
	II	7-8	4.42	0.075	1.70							
	II	12	4.42	0.085	1.92		20.7	.142	3.21			

REMARKS:

CR-115568
SVHSER-6040

REPORT NO.

F-16

Hamilton Standard — Division of United Aircraft Corporation
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LOG OF TEST
ENGINEERING LABORATORIES

RIG NO. 88
TYPE OF TEST HS-C SERIES III
W.P.I. NO.

2000gm HSC or 4.4 LBS.

PLAN OF TEST NO.
SERIAL NO.
PART NO.

SHEET 1 of 9
DATE 2-23-72
ENGINEER
OPERATORS RJC, DRM

DATE 2-23-72	TIME	CYCLE NO	FT LEFT ON ROLL	HRS SINCE START	LBS WT CO_2 BEGIN ADS	LBS ΔCO_2 END ADS	LBS WT AIR END ADS	LBS Δ AIR END ADS	MIN ADS TIME	MIN DES TIME	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOL	°F INLET DEW PT	in H_2O CAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	mm Hg INLET PCO_2	% SCALE COOLANT FLOW	LBS CO_2 REMOVED	% CO_2 REMOVAL	% H_2O REMOVAL	LBS H_2O REMOVED	% H_2O CARRYOVER
23	1228	1	47	0	132.605	.095	—	—	30	40.	10	70	70	50	2.5	14.6	40.5	5.0						
23	1358	2	46	1.1	132.51	.095	—	—	30	42	10	70	70	48	2.5	14.55	40	4.9						
23	1514	3	45	2.4	132.415	.095	—	—	30	42	15	70	70	50	2.6	14.42	40	5.1						
23	1628	4	44	3.7	132.325	.090	168.13	—	32	42	15	70	70	51	2.7	14.6	40	5.0						
23	1730	5	43	4.9	132.235	.09			32	38	10	70	70	51	2.6	14.6	40	5.0						
23	1842	6	42	6.1					30	41	15	70	70	51	2.6	14.63	40	5.0						
23	1954	7	41	7.3					30	40	15	70	70	51	2.6	14.63	40	4.95						
23	2104	8	40	8.5					30	40	12	70	70	51	2.7	14.63	40	5.0						
23	2216	9	39	9.7					30	40	10	70	70	51	2.7	14.63	40	4.95						
23	2327	10	38	10.8					30	40	12	70	70	51	2.7	14.63	40	5.0						
24	0037	11	37	12.0					30	38	10	70	70	51	2.6	14.62	40	4.95						
24	0151	12	36	13.2					30	40	12	70	70	51	2.7	14.62	40	4.95						
24	0302	13	35	14.4					30	38	12	70	70	51	2.7	14.61	40.5	5.0						
24	0413	14	34	15.6					30	40	12	70	70	51	2.6	14.62	40.5	5.0						
24	0524	15	33	16.8					30	40	10	70	70	51	2.7	14.60	40.5	5.0						
24	0636	16	32	18.0					31	40	10	70	70	51	2.7	14.61	40.5	5.0		1.160/13 = .089	2.02	32.1	.235	5.34
24	0748	17	31	19.2					30	40	8	70	70	51	2.7	14.61	40.5	5.0						
24	0858	18	30	20.4	131.075	1.160	165.99	2.48	30	40	10	70	70	51	2.8	14.61	40.5	5.0						
24	1021	19	29	21.7	131.080 130.990	.090			41	40	10	70	70	51	2.7	14.6	40	5.0						
24	1140	20	28	23.1	130.910	.090	165.75	.49	42	40	15	70	70	51	2.7	14.61	40	5.0						
24	1304	21	27	24.5	—	—				40	15	70	70	51	2.7	14.61	40	5.0						
[illegible]	1426	22	25	25.8	130.720 ①	.180			40	40	12	70	70	51	2.7	14.61	40	4.95						
24	1548	23	24	27.2	130.6[illegible]	.090	164.60	.850	40	40	10	70	70	51	2.7	14.61	40.5	4.95						

REMARKS ① NEW CO_2 BOTTLE WT 134.380 INSTALLED

CR-115568
SVHSER-6040

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 2 OF 9
DATE 2-24-72
ENGINEER PJS DRM
OPERATORS

RIG NO. 98
TYPE OF TEST H5-C SERIES III
W.P.I. NO.

2000 gms H5-C (4.4 #)

PLAN OF TEST NO.
SERIAL NO.
PART NO.

Feb 72	TIME	CYCLE NO.	FT LEFT ON BELL	HRS SINCE START	LBS WT CO2 BEGIN ADS	LBS ΔCO2 END ADS	LBS WT AIR END ADS	LBS ΔAIR END ADS	MIN ADS TIME	MIN DES TIME	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOLANT	°F INLET DEW POINT	"H_2O CAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	MMHg INLET PCO_2	% SEAL COOLANT FLOW		LBS CO_2 REMOVED	% CO_2 CAP.	% H_2O REMOVAL	LBS H_2O REM.	% H_2O CAP.	
	1712	24	23	28.6	134.360				40	40	10	70	70	51	2.8	14.4	40	4.95	–							
24	1834	25	22	30.0					40	40	10	70	70	51	2.7	14.4	40	4.95	–							
24	1956	26	21	31.3					40	40	10	70	70	51	2.7	14.4	40.5	5.0	–							
24	2118	27	20	32.7					40	40	10	70	70	51	2.7	14.4	40.5	5.0	–							
24	2240	28	19	34.1					40	40	10	70	70	51	2.7	14.4	40.5	5.0	–							
24	2404	29	17	35.4					40	40	10	70	70	51	2.7	14.4	40.5	5.0	–							
25	0126	30	16	36.8					40	40	10	70	70	51	2.7	14.4	40.5	4.95	–		$\frac{1.080}{12}$:0[illegible]	2.03	26.0	.2635	5.76	
25	0248	31	15	38.2					40	40	10	70	70	51	2.7	14.4	40.5	5.0	–							
25	0410	32	14	39.6					40	40	10	70	70	51	2.7	14.4	40	5.0	–							
25	0533	33	13	41.0					40	40	10	70	70	51	2.7	14.4	40.5	5.0	–							
25	0656	34	12	42.3					40	40	10	70	70	51	2.7	14.4	40.5	4.95	–							
25	0818	35	11	43.7	[illegible]	1.080	16240	2.20	40	40	10	70	70	51	2.7	14.4	40.5	4.95	33							
25	0943	36	9	45.1	133.30	.090	162.22	.18	40	40	10	71	71	51	2.8	14.4	40.5	5.0	32							
25	1102	37	8	46.4	133.20	.090	162.03	.19	40	40	10	71	71	51.5	2.8	14.43	40.5	5.0	32							
25	1227	38	7	47.8	133.[illegible]	.085	161.88	.15	40	40	25	72	72	51	2.9	14.43	41	5.0	33							
25	1352	39	6	49.3	133.035	.080	161.67	.21	40	40	35	70	70	51	2.7	14.4	40.5	4.95	35							
25	1506	40	5	50.8	132.755	.080			30	30	28	75	75	48.5	1.1	14.58	17.5	5.0	-							
25	1615	41	4	51.8	132.875	.080			30	30	10	75	75	48	1.1	14.58	17	5.0	-							
25	1715	42	3	52.8	132.805	.070			30	30	15	74	74	49	1.1	14.54	17	5.0	–							
25	1834	43	64	54.1					30	30	15	75	75	48	1.1	14.6	17	5.0	-							
25	1936	44	63	55.1					30	30	15	75	75	48	1.1	14.57	17	5.0	-							
25	2037	45	63	56.1					30	30	15	75	75	47	1.1	14.56	17	5.0	–							
25	2142	46	62	57.2					30	30	18	75	75	47	1.1	14.55	17	5.0	-							

REMARKS

CR-115568
SVHSER-6040

PAGE NO. F-17

REPORT NO.

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • U.S.A.

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LOG OF TEST
ENGINEERING LABORATORIES

SHEET 3 OF 9
DATE 2-25-72
ENGINEER PJS DLM
OPERATORS

BLDG NO. 8 E
TYPE OF TEST HS-C SERIES III
W.P.I. NO.

PLAN OF TEST NO.
SERIAL NO.
PART NO.

Feb 72	UNITS ► TIME	CYCLE NO.	FT LEFT ON CELL	HRS SINCE START	LBS WT. CO_2 BEGIN ADS	LBS Δ CO_2 END ADS	LBS WT AIR END ADS	LBS Δ AIR END ADS	MIN ADS TIME	MIN DES TIME	μ VAC END DES	°F INLET AIR	°F INLET CAN COOLANT	°F INLET D.P.	"H_2O CAN ΔP	PSIA ADS. PRESS.	CFM ADS FLOW	mm Hg INLET PCO_2	% SENS COOLANT FLOW
25	2244	47	61	58.2					30	30	15	74	74	46	1.0	14.54	17	5.0	–
25	2348	48	60	59.3					30	30	15	75	75	46	1.0	14.53	17	5.0	–
26	0051	49	59	60.3					30	30	15	75	75	45	1.0	14.55	17	5.0	–
26	0155	50	58	61.4					30	30	15	74	74	46	1.0	14.54	17	5.0	–
26	0256	51	58	62.4					30	30	20	74	74	47	1.0	14.54	17	5.0	–
26	0358	52	57	63.5					30	30	20	74	74	46	1.0	14.54	17	5.0	–
26	0500	53	56	64.5					30	30	20	74	74	45	1.1	14.56	17	5.0	–
26	0603	54	55	65.5					30	30	15	74	74	46	1.1	14.56	17	5.0	–
26	0705	55	54	66.6					30	30	12	74	74	46	1.1	14.56	17	5.0	–
26	0807	56	53	67.6					30	30	15	74	74	64	1.0	14.56	17	5.0	–
26	0909	57	52	68.6					30	30	10	74	74	64	1.1	14.56	17	5.0	–
26	1012	58	51	69.7		1.225	158.17	3.50	30	30	12	75	75	44	1.1	14.56	17	5.0	–
26	1114	59	51	70.7	131.425	.095	173.28	.20	30	30	10	76	76	45	1.1	14.47	17	5.0	–
26	1217	60	50	71.8	131.315	.080	173.08	.20	30	30	8	75	75	45	1.1	13.68	17	5.0	–
26	1319	61	49	72.8	131.325	.07	172.92	.16	30	30	10	74	74	49	1.0	13.5	17	5.0	–
26	1421	62	48	73.9					30	30	20	74	74	50	0.9	13.5	17	5.0	–
26	1524	63	47	74.9	131.17	.155			30	30	10	74	74	50	1.0	14.1	17	4.95	–
26	1621	64	46	75.8	131.09	.08	172.41	.51	30	30	20	74	74	52	1.0	14.1	17	4.95	–
26	1723	65	45	76.9	131.019	.08	172.21	.20	30	30	15	74	74	52	1.0	14.1	16	4.95	–
26	1826	66	44	77.9	RESET 130.78				30	30	15	74	74	52	1.0	14.13	16	4.95	–
26	1928	67	44	79.0					30	30	12	73	73	52	1.0	14.13	16	4.90	–
26	2030	68	43	80.0					30	30	15	74	74	52	1.0	14.13	16	4.90	–
26	2132	69	42	81.0					30	30	15	74	74	52	1.0	14.13	16	4.90	–

REMARKS

CR-115568
SVHSER-6040

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION — UA

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LOG OF TEST

ENGINEERING LABORATORIES

SHEET 4 OF 9

DATE 2-26-72

ENGINEER PJS

OPERATORS PJS DPM

BO NO. 88

TYPE OF TEST HS-C SERIES III

W.P.I. NO.

PLAN OF TEST NO.

SERIAL NO.

PART NO.

Date 2/72	TIME	CYCLE NO.	FT LEFT ON BILL	HRS SINCE START	LBS CO_2 INITIAL ADS.	LBS ΔCO_2 END ADS	LBS AIR END ADS.	LBS Δ AIR END ADS.	MIN ADS. TIME	MIN DESORB TIME	μ VAC END DES.	°F INLET AIR	°F INLET CAN COOLANT	°F INLET D.P.	"H_2O CAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	mmHg INLET PCO_2	% SCALE COOLANT FLOW		LBS CO_2 REMOVED	% CO_2 EFF.	% H_2O REM.	LBS H_2O REM.	% H_2O EFF.		
26	2234	70	41	82.1					30	30	15	74	74	52	1.0	14.12	16	4.95	–								
26	2336	71	40	83.1					30	30	12	74	74	52	1.0	14.12	16	4.90	–								
27	0039	72	39	84.1					30	30	15	74	74	52	1.0	14.12	16	4.95	–								
27	0142	73	38	85.2					30	30	15	74	74	52	1.0	14.12	16	4.95	–								
27	0244	74	38	86.2					30	30	15	74	74	52	1.0	14.12	16	4.95	–								
27	0346	75	37	87.3					30	30	18	74	74	52	1.0	14.12	16	4.95	–								
27	0449	76	36	88.3					30	30	15	74	74	52	1.0	14.12	16	4.95	–								
27	0551	77	35	89.3					30	30	15	74	74	52	1.0	14.12	16	4.95	–								
27	0653	78	34	90.4					30	30	20	74	74	52	1.0	14.12	16	4.95	–								
27	0755	79	33	91.4					30	30	15	74	74	52	1.0	14.12	16	4.95	–								
27	0857	80	32	92.7	[illegible]	1.265	169.51	1.90	30	30	15	74	74	52	1.0	14.12	16	4.95	–								
27	1000	81	32	93.5	129.715				30	30	15	74	74	52	1.0	14.12	16	4.95	35								
27	1102	82	31	94.5	[illegible]	.155	169.00	.31	30	30	15	74	74	52	1.0	14.12	16	4.95	34								
27	1204	83	30	95.6	129.580	.08	168.82	.18	30	30	15	74	74	52	1.0	14.12	16	4.95	35		.08	1.82	42.0	.1597	3.63		
27	1306	84	29	96.6	129.460	.08	168.65	.17	30	30	15	74	74	52	1.0	14.12	16	4.95	35								
27	1408	85	28	97.6	129.400	.085	168.49	.16	30	30	15	74	74	52	2.7	14.15	40	4.95	34								
27	1510	86	27	98.7	129.315	.080	168.34	.15	30	30	17	74	74	52.5	2.7	14.2	39.5	4.95	34								
[illegible]	1613	87	26	99.7	129.235				30	30	20	74	74	54	2.7	14.2	39.5	4.9	–								
27	1715	88	26	100.8					30	30	20	74	74	53	2.7	14.2	39.5	4.9	–								
27	1817	89	25	101.8					30	30	17	74	74	54	2.7	14.2	39.5	4.9	–								
27	1920	90	24	102.8					30	30	18	74	74	53	2.7	14.2	39.7	4.95	–								
27	2022	91	23	103.9					30	30	17	74	74	53	2.7	14.2	39.7	4.95	–								
27	2124	92	22	104.9					30	30	15	74	74	53	2.7	14.2	39.7	4.95	–								

REMARKS

CR-115568

SVHSER-6040

PAGE NO.

REPORT NO.

Hamilton Standard — U A.

WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 5 OF 9
DATE 2-27-72
ENGINEER RJS DRM
OPERATORS

RIG NO. EE
TYPE OF TEST HS-C SERIES III
W.P.I. NO.
PLAN OR TEST NO.
SERIAL NO.
PART NO.

F-20

DATE	TIME	CYCLE NO.	FT LEFT ON ROLL	HRS SINCE START	LBS WT. CO2 BIRD ADS	LBS ΔCO2 ADSORB.	LBS WT. AIR END ADS	LBS ΔAIR END ADS	MIN ADS TIME	MIN DES. TIME	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOLANT	°F INLET DEW POINT	"H2O CAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	mm Hg INLET PCO2	% SCALE COOLANT FLOW
27	2226	93	21	105.9					30	30	16	74	74	53	2.7	14.2	39.5	4.95	–
27	2328	94	20	107.0					30	30	15	74	74	53	2.7	14.2	39.5	4.95	–
28	0031	95	19	108.0					30	30	15	74	74	53	2.7	14.2	39.5	4.95	–
28	0133	96	19	109					30	30	15	74	74	53	2.7	14.2	39.5	4.95	–
28	0235	97	18	110.1					30	30	15	74	74	53	2.7	14.2	39.5	4.95	–
28	0338	98	17	111.1					30	30	20	74	74	53	2.7	14.2	39.5	4.95	–
28	0440	99	16	112.2					30	30	20	74	74	53	2.7	14.2	39.5	4.95	–
28	0542	100	15	113.2					30	30	18	74	74	53	2.7	14.2	39.5	4.95	–
28	0644	101	14	114.2					30	30	20	74	74	53	2.7	14.18	39.5	4.95	–
28	0747	102	13	115.3		1.295	165.64	2.70	30	30	18	74	74	53	2.7	14.18	39.5	4.95	35
28	0849	103	12	116.3	122.74	.080	165.41	.17	30	30	18	74	74	53	2.7	14.18	39.5	4.95	34
28	0952	104	12	117.4	122.86	.080			30	30	18	74	74	53	2.7	14.18	39.5	4.9	–
28	1053	105	11	118.4	122.12	.130			30	47	20	74	74	53	2.7	14.18	39.5	4.9	–
28	1212	106	10	119.8	122.65				30	30	40	73	73	50.5	2.7	14.05	39.5	4.95	–
28	1314	107	9	120.8		.125	164.71	.76	30	30	50	73	73	50.5	2.7	14.15	39.5	4.95	35
28	1417	108	8	121.9	122.525	.080	164.54	.17	30	30	40	73	73	51	2.7	14.15	39.5	4.95	34
28	1519	109	7	122.9	122.445				30	30	40	73	73	51	2.7	14.15	39.5	4.95	–
28	1624	110	6	123.9		.160	164.12	.36	30	30	40	73	73	51	2.7	14.15	39.5	4.95	34
28	1725	111	97	124.9	122.285				30	30	50	72	72	60	2.6	14.15	39.5	4.95	–
28	1822	112	96	126.0					30	30	40	72	12	51	2.6	14.15	39.5	4.95	–
28	1930	113	95	127.0					30	30	30	72	72	50	2.6	14.14	39.5	4.95	–
28	2032	114	94	128.0					30	30	30	72	72	51	2.65	14.15	39.5	4.95	–
28	2135	115	93	129.1					30	30	30	72	72	51	2.6	14.16	39.5	4.95	

REMARKS:

CR-115568
SVHSER-6040

Hamilton Standard — U A.
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 6 OF 9
DATE 2-29-72
ENGINEER RJS DRM
OPERATORS

BID NO. 8E
TYPE OF TEST HS-C SERIES III
W.P.I. NO.
PLAN OF TEST NO.
SERIAL NO.
PART NO.

TIME	CYCLE NO	FT LEFT IN CELL	HRS SINCE START	LBS WT CO2	LBS DEC	LBS WT AIR END	LBS AIR END	MIN ABS TIME	MIN DESORB TIME	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOLANT	°F INLET D.P.	"H2O CAN ΔP	PSIA ABS PRESS	CFM ABS FLOW	mm Hg INLET PCO2	% SCALE COOLANT FLOW	LBS CO2 REMOVED	% CO2 EFF	% H2O REM	LBS H2O REM	% H2O EFF
28 2237	116	92	130.1					30	30	20	70	73	51	2.7	14.15	39.5	4.90	–					
28 2339	117	91	131.2					30	30	*	70	73	51	2.7	14.15	39.5	4.95	–					
29 0042	118	90	132.2					30	30	*	70	73	51	2.7	14.09	40	5.0	–					
29 0144	119	89	133.2					30	30	*	70	73	51	2.7	14.09	39.5	5.1	–					
29 0246	120	88	134.3					30	30	*	70	72	51	2.7	14.07	39.5	5.0	–					
29 0349	121	87	135.3					30	30	*	70	72	51	2.7	14.08	40	5.1	–					
29 0451	122	86	136.4					30	30	*	70	73	51	2.7	14.07	40	5.0	–					
29 0553	123	86	137.4					30	30	*	70	73	51	2.7	14.09	40	5.1	–					
29 0655	124	85	138.4					30	30	*	70	73	52	2.7	14.10	39.5	5.1	–					
29 0757	125	84	139.5		.610	161.62	2.56	30	30	*	70	73	52	2.6	14.17	39.5	4.95	–					
29 0900	126	83	140.5	126.605	.075	161.43	.19	30	30	12	70	73	51	2.6	14.18	39.5	4.85	35					
29 1002	127	82	141.5	126.600	.090	161.25	.18	30	30	12	70	72	51	2.6	14.87	39.5	4.90	34					
29 1105	128	81	142.6	126.570	.080	161.06	.19	30	30	18	70	73	51	2.6	14.40	39.5	4.95	35					
29 1207	129	80	143.6	126.490				30	30	10	70	72	52	2.6	14.4	39.5	4.95	–					
29 1309	130	79	144.7		.160	160.71 160.48	.35	30	30	15	70	73	51	2.5	14.4	39.5	4.95	35					
29 1412	131	79	145.7	126.200	.075	162.05	.23	30	30	10	70	73	51	2.7	14.4	39.5	4.95	34					
29 1515	132	78	146.7	126.205	.080	162.45	.20	30	30	12	70	73	51	2.6	14.25	39.5	4.95	36	.080	1.82	27.9	.014	4.87
29 1617	133	77	147.8	126.125	.085	162.25	.20	30	30	12	70	73	51.5	2.6	14.28	39.5	4.95	35					
29 1719	[illegible]4	76	148.8	126.0*				30	30	15	70	73	52	0.5	14.13	13	4.95	–					
29 1822	135	75	149.9					30	30	12	70	73	51	0.5	14.18	13	4.95	–					
29 1924	136	74	150.9					30	30	15	70	73	51	0.5	14.18	13	4.95	–					
29 2026	137	73	151.9					30	30		70	73	51	0.5	14.16	13	4.95	–					
29 2129	138	73	153					30	30		70	73	51	0.5	14.15	13	4.9	–					

REMARKS * VACUUM SYSTEM FAILURE

CR-115568
SVHSER-6040

F-21

F-22

Hamilton Standard — U A.
WINDSOR LOCKS, CONNECTICUT • U.S.A.

OG OF TEST
ENGINEERING LABORATORIES

SHEET 7 OF 9
DATE 2-29-72
ENGINEER
OPERATORS RJS DRM

RIG NO. BB
TYPE OF TEST HS-C SERIES III
W.P.I. NO.
PLAN OF TEST NO.
SERIAL NO.
PART NO.

FEB 72	TIME	CYCLE NO	FT LEFT IN CELL	HRS SINCE START	LBS WT CO_2 BOTTLE ADS	LBS ΔCO_2 AFTER ADS	LBS WT AIR AFTER DES	LBS Δ AIR AFTER DES	MIN TIME ADS	MIN TIME DES	μ VACUUM END DES	°F INLET AIR	°F INLET CAN COOLANT	°F INLET D.P.	"H_2O CAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	mm Hg INLET CO_2	% SENS COOLANT FLOW
29	2232	139	72	154					30	30	10	70	73	51	0.5	14.15	93	4.9	—
29	2354	140	71	155.1					30	30	10	70	73	51	0.5	14.15	93	4.9	—
1	0037	141	70	156.1					30	30	12	70	73	51	0.5	14.15	93	4.9	—
1	0139	142	69	157.1					30	30	10	70	73	51	0.5	14.18	93	4.9	—
1	0242	143	68	158.2					30	30	15	70	73	51	0.5	14.18	93	4.9	—
1	0344	144	67	159.2					30	30	20	70	73	50.5	0.5	14.18	93	4.9	—
1	0447	145	67	160.3					30	30	10	70	73	51	0.5	14.18	93	4.9	—
1	0549	146	66	161.3					30	30	15	70	73	51	0.5	14.18	93	4.9	—
1	0652	147	65	162.4					30	30	10	70	73	51	0.5	14.18	93	4.9	—
1	0754	148	64	163.4		1.075	164.62	2.63	30	30	12	70	73	51	0.5	14.18	93	4.9	—
1	0857	149	63	164.4	124.765	.075	164.43	.19	30	30	12	70	73	51	0.5	14.16	93	4.95	37
1	1035	150	62	166.0	124.890	.080	164.29	.19	40	40	12	70	78	51	2.7	14.23	40	4.9	38
1	1157	151	60	167.4	124.810	.080	164.07	.17	40	40	12	70	73	51	2.7	14.29	41	4.95	—
1	1320	152	59	168.8	124.730*	~~[illegible]~~	163.92	.15	40	40	10	70	73	51	2.7	14.25	41	4.95	35
1	1444	153	58	170.2	125.310*	.085	163.75	.17	40	40	12	70	73	51.5	2.7	14.22	41	4.95	35
1	1608	154	57	171.6	124.910				40	40	15	70	73	51.5	2.6	14.2	41	4.95	34
1	1731	155	56	173.0					40	40	10	70	73	51.5	2.6	14.2	41	4.95	—
1	1855	156	55	174.4					40	40	12	70	73	51.5	2.6	14.2	41	4.95	—
1	2019	157	54	175.8					40	40	10	70	73	51	2.6	14.2	41	4.95	—
1	2142	158	52	177.2					40	40	10	70	73	52	2.6	14.2	41	4.95	—
1	2306	159	51	178.6					40	40	10	70	73	52	2.6	14.2	41	4.95	—
2	0030	160	50	180					40	40	10	70	73	52	2.6	14.2	41	4.95	—
2	0153	161	49	181.4					40	40	10	70	73	51.5	2.6	14.2	41	4.95	—

REMARKS * READJUSTED CO_2 BOTTLE SUPPORT

CR-115568
SVHSER-6040

Hamilton Standard U A.
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 8 OF 9
DATE 3-2-72
ENGINEER
OPERATORS PJF DRM

RIG NO. 8E
TYPE OF TEST HS-C SERIES III
W.P.I. NO.
PLAN OF TEST NO.
SERIAL NO.
PART NO.

DAY	TIME	CYCLE NO	FT LOFT CELL	HRS SINCE START	LBS WT CO2 SORBENT	LBS ΔCO2 END	LBS WT AIR FLOW	LBS ΔAIR FLOWS	MIN TIME ADS	MIN TIME DES	# COOLANT FLOW	°F INLET AIR	°F INLET COOLANT	°F INLET D.P.	"H2O CAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	mm Hg INLET PCO2	% SOLN COOLANT FLOW		LBS CO2 REM.	% CO2 CAP.	% H2O REM.	LBS H2O REM.	% H2O CAP.
2	0317	162	48	182.8					40	40	10	70	73	51.5	2.6	14.2	41	4.95	–						
2	0441	163	47	184.2					40	40	10	70	73	51.5	2.6	14.2	41	4.95	–						
2	0605	164	45	185.6					40	40	10	70	73	51.5	2.6	14.2	41	4.95	–						
2	0725	165	44	187		1.000	161.65	2.10	40	40	10	70	73	51.5	2.6	14.2	41	4.95	34						
2	0934	166	43	189.1	123.910	.105	161.48	.17	40	85	6	70	72.5	51	2.6	14.2	41	4.9	35						
2	1058	167	41	190.5	123.805	.090	161.31	.17	40	40	10	70	72.5	51	2.6	14.2	41	4.95	34						
2	1222	168	40	191.9	123.715	.080	161.12	.19	40	40	12	70	72	51	2.6	14.2	41	4.95	–						
2	1347	169	39	193.3	123.635	.080	–		40	40	10	70	72.5	51.5	2.6	14.22	41	4.95	–						
2	1538	170	38	195.1	123.555	.085	160.75	.37	40	40	12	70	72.5	51.5	2.6	14.22	41	4.95	35						
2	1702	171	36	196.5	123.470				40	40	12	70	72.5	51.5	2.5	14.2	41	4.95	–						
2	1826	172	35	197.9					40	40	10	70	72.5	51	2.5	14.2	41	4.95	–						
2	1950	173	34	199.3					40	40	15	70	72.5	51	2.5	14.2	41	4.95	–						
2	2107	174	33	200.7					40	40	15	70	72.5	51	2.5	14.2	41	4.95	–						
2	2237	175	32	202.1					40	40	18	70	72.5	51	2.5	14.2	41	4.95	–						
3	0001	176	31	203.5					40	40	15	70	72.5	51	2.5	14.2	41	4.95	–						
3	0126	177	29	204.9					40	40	20	70	72.5	51	2.5	14.2	41	4.95	–						
3	0249	178	28	206.3					40	40	15	70	72.5	51	2.5	14.2	41	4.95	–						
3	0412	179	27	207.7					40	40	20	70	72.5	51	2.5	14.2	41	4.95	–						
3	0537	180	26	209.1					40	40	15	70	72.5	51	2.5	14.2	41	4.95	–						
3	0701	181	25	210.5		.895	158.70	2.05	40	40	15	70	72.5	51	2.5	14.2	41	4.95	–						
3	0825	182	23	211.9	122.505	.070	158.51	.19	40	40	15	70	72.5	51	2.4	14.2	41	4.95	35						
3	0949	183	22	213.3	122.500	.095			40	40	20	70	72	50.5	2.5	14.2	41	4.9	–						
3	1111	184	21	214.7	122.410	.080	158.12	.39	40	40	15	70	72.5	50.5	2.5	14.2	41	4.9	–		.08	1.82	22.5	.2285	5.2

REMARKS

CR-115568
SVHSER-6040

F-23

Hamilton Standard — U/A

WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 2 OF 9
DATE 3-3-75
ENGINEER
OPERATORS PJT DRM

BG NO. 88
TYPE OF TEST HS-C SERIES III
W.P.I. NO.

PLAN OF TEST NO.
SERIAL NO.
PART NO

UNITS →	TIME	CYCLE NO.	FT	HRS SINCE START	LBS WT CO2	LBS ΔCO2	LBS WT AIR	LBS Δ AIR	MIN ADS TIME	MIN DES TIME	μ VACUUM	°F INLET AIR	°F INLET DEW POINT	°F INLET DP	"H2O BAN ΔP	PSIA ADS PRESS	CFM ADS FLOW	mm Hg INLET PCO_2	% SCALE		LBS CO_2 REM	% CO_2 CAP	% H_2O REM	LBS H_2O REM	% H_2O CAP	
3	1236	185	20	216.1	122.330	.08	157.96	.16	40	40	15	70	87	56	2.5	14.25	41	4.95	—							
3	1401	186	19	217.5	122.250	.09	157.80	.16	40	40	15	70	81	56	2.6	14.2	41	4.95	3%							
3	1524	187	18	218.7	122.160	.090	~~157.xx~~		40	40	10	70	81	56.5	3.6	14.25	50	5.15	–							
3	1647	188	17	220.3	122.070	.090	157.42	.38	40	40	10	70	81	56.5	3.6	14.25	50	5.15	3%							
3	1811	189	15	221.7	121.950				40	40	10	70	81	56	3.5	14.25	50	7.1	–							
3	1934	190	14	223.1	① 121.770				40	40	10	70	81	56.5	3.5	14.25	50	7.1	–		$\frac{.550}{6} \div .0225$	2.3	11.2	.1665	4.16	②
3	2057	191	13	224.5					40	40	12	70	81	56	3.5	14.25	50	7.1	–							
3	2221	192	12	225.9					40	40	15	70	81	56	3.5	14.25	50	7.1	–							
3	2345	193	11	227.3					40	40	15	70	81	56	3.5	14.25	50	7.1	–							
4	0107	194	10	228.7		.555			40	40	12	70	81	56	3.5	14.03	50	7.1	–							
	0233*				121.435																					

REMARKS ① REZERO CO_2 SCALE
* VACUUM VALVE FAILURE, SYSTEM AUTOMATICALLY SHUT DOWN
② HS-C WT. ESTABLISHED AT 4.0" AFTER TEST. 0.4" LOST TO VACUUM SYSTEM THROUGH FAILED BED SEAL.

CR-115568
SVHSER-6040